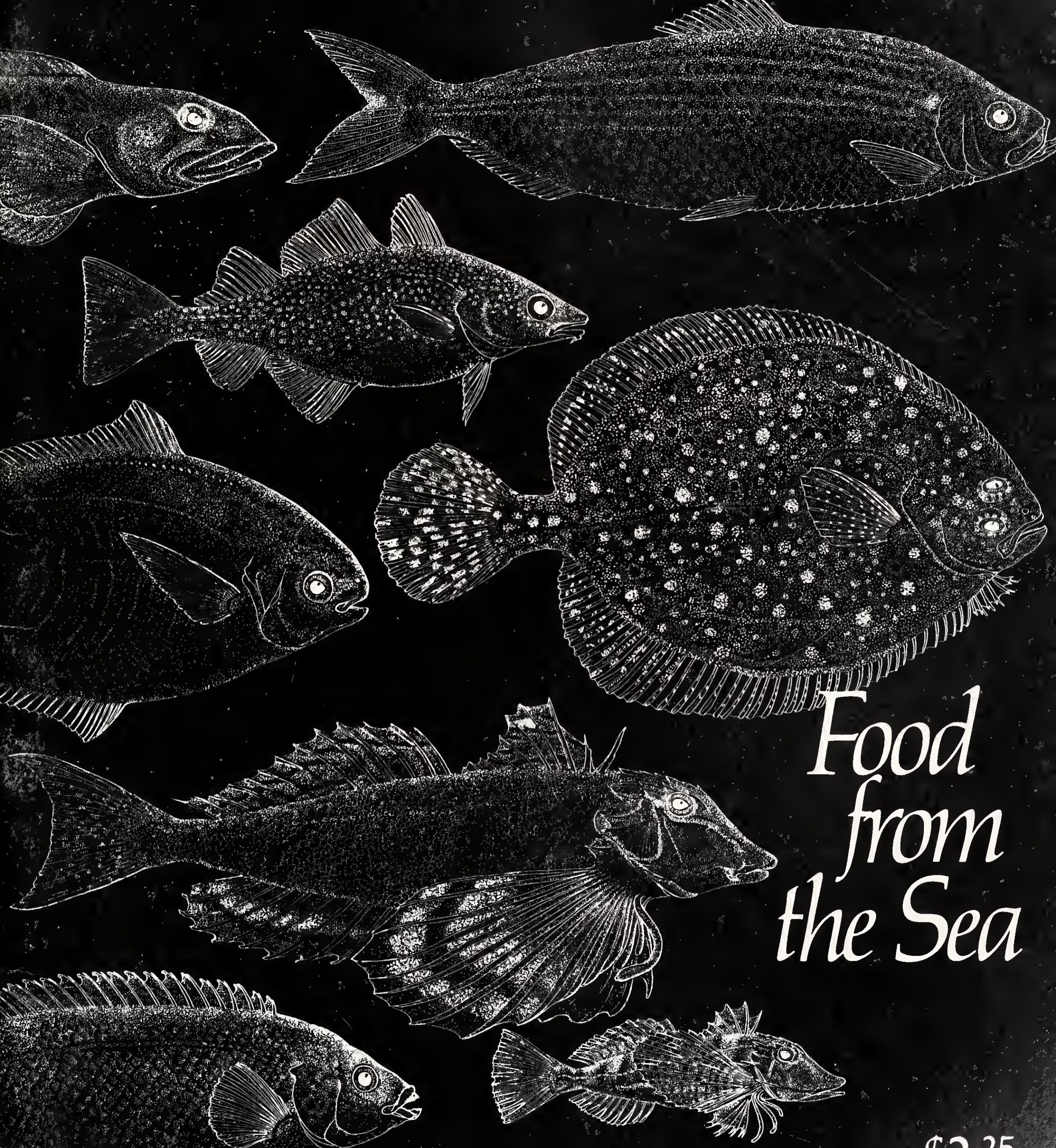
Oceanus

Winter 1975



Food from the Sea

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Cover: Drawings by Tor Hansen (see inside back cover).

Commentary

The Vineyard Catch

They went into the oak woods to cut the trap spiles that they drove in spring in Vineyard Sound, starting a little way from shore and extending into deep water. The line of spiles was strung with a net known as a leader, so that fish swimming along shore would strike it, turn seaward, and enter the heart of the trap from which the pound fishermen pursed them up and bailed them into dories.

Once there were twenty-seven locations where spiles and leaders intercepted the run of fish. The traps made tremendous catches—scup, squeteague (considered common and cheap), bonito, bluefish, butterfish, mackerel, flounder, sea bass. Waste fish such as sea robins, squid, and dogfish went to the lobstermen as bait.

But all this was a long time ago. As a boy I heard complaints that traps at Seconnet on the Rhode Island shore were putting the Vineyard fishermen out of business. Yet as long ago as 1871 the *Vineyard Gazette* had reported: "The pounds of the North Shore are pounding the life out of every poor fish which comes within reach of their insatiable maws. Since their introduction along the coast the sight of scup, tautog and bluefish in our harbor is as scarce as silver and gold money."

The days of the pounds was over by 1909 or 1910, except for the spring run of scup, which sustained a marginal few. Commercially viable lobstering in Vineyard Sound did not last long either. My uncle, Capt. B. C. Cromwell, predicted the virtual extinction of the lobster, and my father said to him, "What are you going to do, Ben?" My uncle replied, "I'm going to eat 'em as long as I can get 'em."

How much we have seen without really seeing it at all, and without putting separate events into any logical whole. We were onlookers at themes that run through this issue—exploitation and exhaustion, conversion from traditional and individualistic methods to the power and destruction of technology and the machine.

In 1920 otter-trawling was just coming in. Edgartown, then and for some years later, had a fleet of deep-legged schooners—beautiful craft that fished on Georges Bank and sometimes saw incoming liners close-by in the fog. There was awareness of what otter-trawling would do to the sea bottom, but no real concern.

In spring the schooners sailed south to meet the mackerel, and after that fitted for swordfishing. Boston was the market for swords—New York had not yet discovered them. Here was another strand of the developing threat—expanding markets. In years just before World War II, the appearance of Japanese swordfish in the chain stores led to angry protests. Enough of it was condemned by state health authorities to discourage further imports from Japan.

But the Japanese taught us long-lining, so that swords could be caught all-year, swords of all sizes. There was talk about what this method of fishing would do to the swordfish population, but talk comes to nothing. We knew that drowned swords were inferior, and always insisted on harpooned swordfish when we bought.

A great bed of quahaugs off Nantucket led to quantity shipments, and the boatline enjoyed a prosperous couple of years. But the bed was then exhausted. Sea scalloping came as a great boom, "Deep Sea Scallops" on city restaurant menus resulting in a new demand. But the price of the superior bay scallops was driven down. And no more than quahaugs were sea scallops inexhaustible.

Our schooners yielded to mechanized draggers, the last one at Edgartown sold in 1952, and important operations shifted to New Bedford. Centralization was the thing, and it was no longer an advantage to be a few miles closer to the fishing grounds.

All this we have witnessed on our Island, without putting together any coherent attitude or policy or opinion. So now it is all up to researchers, scientists of all kinds, and—is there hope?—to statesmen.

Henry Beetle Hough, editor of the Vineyard Gazette, *is a long-time resident of Martha's Vineyard.*

Maximum Yield: Assessment and Attainment

Robert Edwards and Richard Hennemuth

Hauling in the cod end of an otter trawl. (Robert K. Brigham, NMFS)

Awareness of the need to practice conservation in fisheries management is nothing new. In thirteenth-century Britain, royal regulations governing salmon fishing in the County of Cumberland required riverine nets to be spaced far enough apart to allow "a sow and her pigs to pass."* This was the "king's gap" through which salmon could escape to spawn. Some three hundred years later, Parliament passed legislation dealing with "the preservation hereafter of spawn, fry, and young . . . which heretofore hath been much destroyed." The principle that fish must be permitted to reproduce and mature was understood, if not always accepted. Competition for the resource was local. The king's authority to regulate the harvest was strong.

Neither conservation needs nor the biological basis of fisheries has changed over the years. It has become much more difficult, however, to implement regulations in the face of heavy demand. The user community is multinational, even on small fishery grounds, and there is no clearly identified central authority to enforce regulations. Governments of the world are now struggling to formulate an international law of the sea, which, among other things, will set the geopolitical stage for worldwide ocean fisheries management (see page 42). They are doing so at a time when the global yearly harvest of aquatic plants and animals is roughly 70 million metric tons, fairly close to the 100 million tons generally conceded to be about the maximum annual yield of traditional species that can be sustained.

It is no longer a question of dealing with local problems. Fisheries throughout the world are in trouble. Many of the traditional ones—herring, cod, haddock, flounder, sardine, etc.—are overfished. That is, they are continually harvested above the net natural rate of production to the point where the population is driven below the size required to produce maximum yields. Though but a few years ago the frontiers of fishing seemed hardly to have been explored, today there is evidence of resource depletion and mismanagement in many areas. The

*S. A. Moore and H. S. Moore, *The History and Law of Fisheries* (London: Stevens and Haynes, 1903).

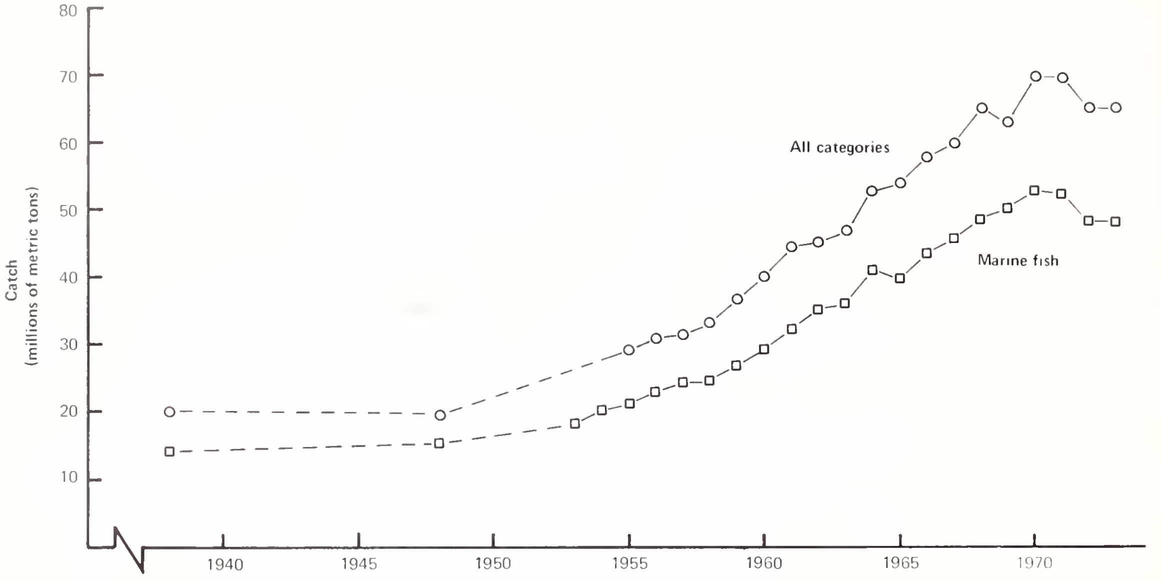

Figure 1. World fisheries catch of all aquatic plants and animals and marine fish. (Adapted from U.N. FAO, Yearbook of Fishery Statistics, *vol. 34, 1972; unpublished FAO data for 1973)*

steady rise in marine fish* catches since World War II, spurred to a considerable extent by the development of distant water fleets of large fishing and support vessels, has faltered in recent years despite increasing effort (Figure 1). Even so, reluctance to curtail development is the order of the day. Indeed, the world catch in recent years has been maintained—barely maintained—by transferring and expanding effort on less heavily exploited species (see page 36).

Many fisheries have come under the aegis of regional management authorities, such as the International Commission for the Northwest Atlantic Fisheries, most if not all of which rely on scientific advice in defining the productive capacity of the resource. Regulatory decisions are based on this advice, then tailored as they must be to take political and social factors into account. Fishery science has progressed over the years from qualitative to quantitative natural history investigation. The biologist has better methods at his disposal to assess both the productivity of fisheries and the effects of fishing. But the results of his sophisticated calculations, which deal with a proliferation of variables, are increasingly difficult to explain. It is a long way from the simplicity of a king's gap to the complexity of a total catch quota, and it is worth asking if today's regulations are any better than were the royal decrees.

*This article deals primarily with finfish populations and not with those at lower trophic levels, e.g., plankton invertebrates such as krill, or marine plants such as algae.

There are concepts that must be clarified if there is to be mutual understanding among fishermen, scientific advisors, managers, and the general public of the tools available to assess potential yields from the sea and of the steps necessary to attain those yields. Such understanding is basic to any rapid development of effective, universally accepted protocols for fisheries management.

Biases in the Curve

The traditional biological approach to the question of productive potential rests on quantifying the natural rates of birth, growth, reproduction, and death. These processes, innate properties of each species, determine the capacity of the population for natural increase. The actual rate of natural increase is modified by other, essentially external, factors—competition, predation, changes in the physical environment. For the most part this net rate is a function of population size; it approaches zero at minimum population sizes, is at its highest at some intermediate size, and again approaches zero as the population approaches its maximum. Thus, there is a self-regulating mechanism that tends to keep the population in bounds.

The weight of fish produced to rebuild a reduced population is surplus in the sense that it is not needed to maintain the lower population size. This surplus represents the so-called "sustainable yields" or "harvestable surplus" (Figure 2). In many cases, however, the potential yield of a fish population is expressed in terms of yield per recruit. In this instance, a recruit is an individual

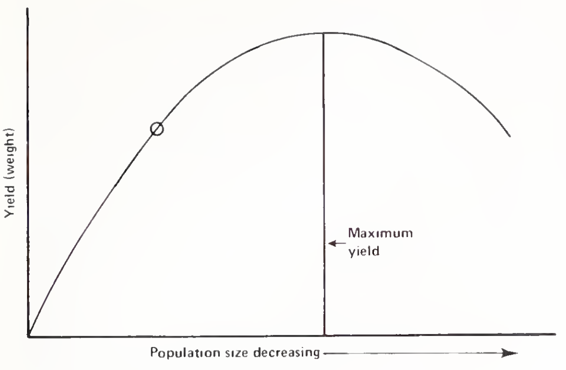

Figure 2. Generalized yield curve.

fish, native or newcomer to an area, that has just become large enough so that it can be caught and kept. The yield expected from this fish depends on its being caught before it dies a natural death, and also on its rate of growth. A fisherman can let the fish grow and gain weight, but a number of these fish will die naturally that might otherwise have been caught. On average, it pays to wait up to a point, because the smaller number of fish caught will be more than compensated for by the greater weight of each individual.

Yield per recruit can be calculated if one knows the rates of growth and death (Figure 3). However, such a calculation does not take population size into account. Because the growth and natural mortality rates of many species generate a curve that is flat-topped, as illustrated, the population size associated with the maximum yield per recruit is sometimes very small—so small, in fact, that there may not be enough fish left to produce a maximum surplus yield. Unfortunately, fisheries managers often regard yield-per-recruit values as interchangeable with calculations of sustainable yields. When that happens, implications of the relationship between stock size and capacity to increase are lost.

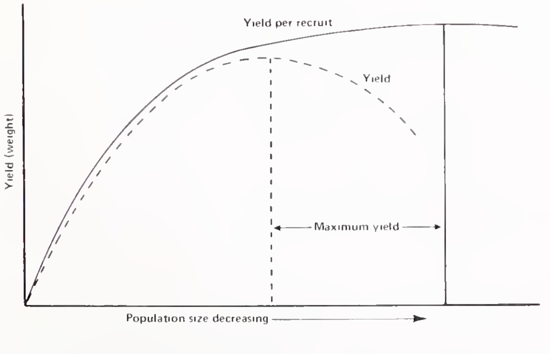

Figure 3. Comparison of yield-per-recruit and yield curves.

The method used for estimating potential yield involves yield curves calculated from data on the actual catch and the amount of fishing effort (number of days or hours fished, amount of gear employed, etc.) expended to get it. Each unit of fishing effort takes a fixed fraction of the population when applied in a standard manner. Fishing effort reduces population size in proportion to the amount being exerted.

There are at least three principal causes of biases that create inaccuracies in the preparation of yield curves and, in turn, skew figures on which allowable catches or permissible levels of fishery effort are based. They are misunderstandings concerning the effort-yield relationship, failure to account for the "learning factor," and failure to account for "delay time."

Curves of fish yield in relation to effort illustrate the important phenomenon of diminishing returns. At the point where total fish harvest reaches about 70 percent of the potential (the open circle in Figure 2), the rate of increase of yield per unit of fishing effort applied begins to drop off rapidly. A little less than half the effort is required to reach this point than to get to the point of maximum yield. This becomes a critical matter when national or fleet goals are set by catch, as is more often the case than not. (Incidentally, it is at about this stage in the development of a fishery management regime that the credibility of the biologist is seriously questioned. While the fisherman sees a continuing bonanza, the scientist is advising caution and curtailment.) Setting goals on the basis of effort rather than catch would be less likely to lead to exceeding the maximum yield, because it would focus attention on the yield-effort relationship.

Only recently, with the rapid development of large fleets, has the learning factor bias become clearly recognized as a significant element in yield analysis. During the first two or three years of a fishery, there is a period of rapidly increasing efficiency as fishermen learn about the distribution and behavior of the fish. The continual increases in catch per unit effort during this phase mask the real population decline and lead to an overestimation of long-term yield.

Accurately estimating the recovery time of a reduced population is particularly important in a new and fast-developing fishery—and particularly susceptible to error. Only when the life history of a species is well understood can this factor be built into calculations with any degree of certainty. When a fishery starts on an unexploited or lightly exploited population, that population's capacity for natural increase is low. The first catches represent almost entirely the amount by which it is reduced. Because of the self-regulating mechanism mentioned

earlier, such a reduced population will have a greater capacity for increase. It will take some years, however, for the increased natural production to become available to the fishery. The longer lived the species, the longer the lag. It can range from one or two years for anchovy to ten or more years for halibut or redfish. Under these circumstances, trying to maintain or increase the catch will cause further reductions in the population. If the development is rapid, the population does not have time to come into balance, and the catches exceed sustainable yield. When catch and effort points calculated under these conditions are used to estimate a sustained yield curve, they will produce inaccuracies unless the delay-time factor is taken into account.

The degree to which the introduction of recovery time into the calculations can change the estimates is well illustrated by data from the fishery off New England, which developed rapidly in the last decade. The yield curves fitted by including a recovery period indicate lower average yields than the observed annual catch/effort ratios indicate (Figure 4). It should also be noted that fisheries often expand because fleets are attracted by short-term high abundance, caused by abnormally large year-classes entering the population or unusually favorable environmental conditions. Yield curves drawn through these points of catch and effort will produce overestimations of potential long-term yield.

By the same token, unfavorable shifts in the environment can affect yield assessments (see page 30). The anchovy fishery in the waters off Peru began about ten years ago and developed quickly to a catch of 12 million metric tons by 1968. The assessment of potential yields completed in 1967 indicated a maximum sustainable total yield of about 10 million tons, to be shared by men and guano birds. During 1972 and 1973, the catch dropped precipitously to below 5 million tons.

It has long been known that every four or five years a change in physical environment occurs in these waters that results in a reduced recruitment of fish and, to some extent, a low availability of fish to fishermen. The exact effects of this environmental shift on the fish population are not well understood. In an unfished situation, the fluctuations in population size might well be less than that indicated by the almost complete collapse of the fishery. When man generates a high mortality in the face of a naturally degrading environment, fishery "disasters" are almost inevitable. In any case, the maximum sustainable yield estimated for the anchoveta is clearly not the average maximum yield that can be

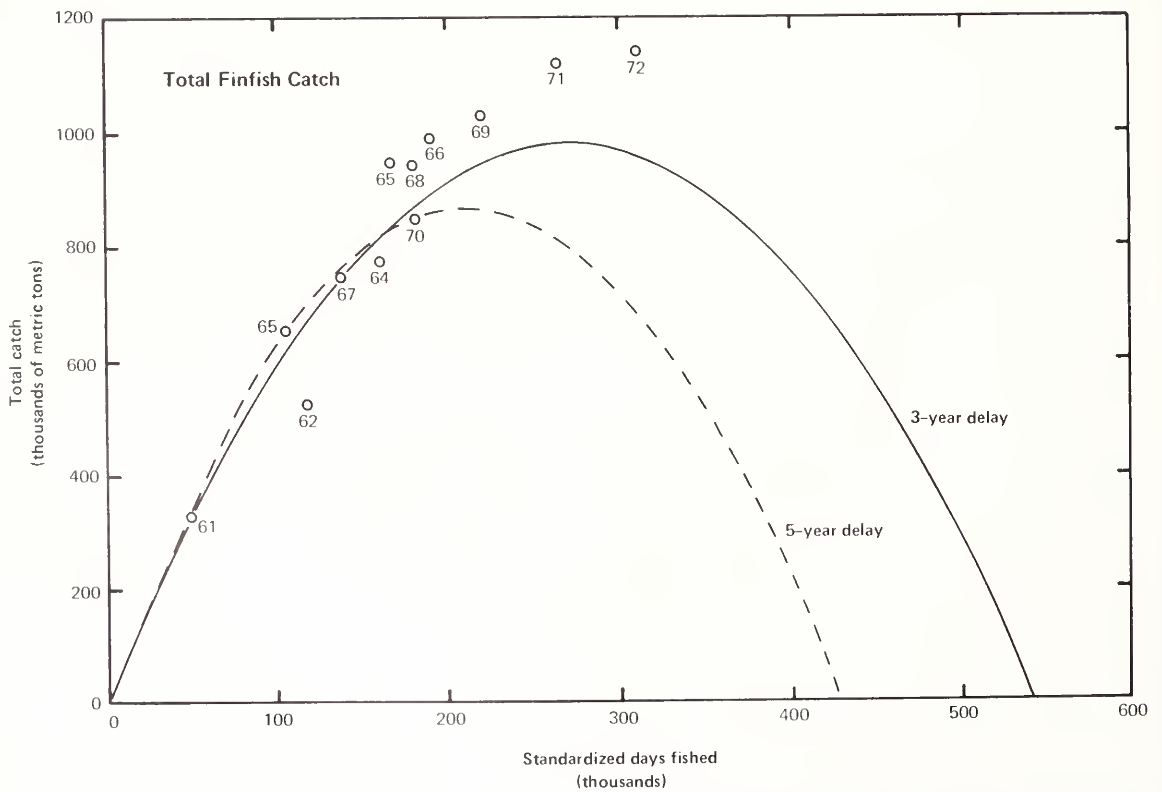

Figure 4. Yield curves for total fishery off New England fitted under two delay-time assumptions. Points are actual annual catches. (ICNAF Redbook, Pt. I, *1973)*

sustained in the long run. Averaging the good years (to which the 1967 assessment applied) with the bad would indicate a much smaller potential yield.

The Mixed Fishery Effects

On many of the richest fishing grounds, a variety of species exists, often in the same place at the same time. Potential yields have generally been based on assessments of individual stocks made at different periods, and the potential total yield from an area has been calculated as the sum of these figures. Yet interspecific effects—predation and competition—almost certainly have a significant influence on the productivity of individual populations.

Over a period of time, populations may interact in a cyclical manner; when some are down, others are up. A fishery concentrating on certain species reduces their abundance and may thus change the interspecific population balance. (It is questionable whether such a causal relationship does in fact exist, but such shifts in relative abundance are observed—in the herring and mackerel of the Northwest Atlantic, to cite one example.) The fishery then shifts its effort to the population that is increasing. If the conventional method of assessing potential yields—toting up yields for individual species—is applied at this point, it will imply a greater total yield than is actually possible at any given time.

Fishery science has not yet progressed to the stage where such effects can be accurately quantified. A first attempt has been made, however, focusing on the fishing areas off New England. Yield curves have been fitted to the total catch of all fish and the total effort of all fleets (Figure 4). These curves imply a maximum sustainable yield of 800,000-900,000 metric tons for the area. The sum of individual species assessments indicates a maximum sustainable yield of 1.1-1.3 million metric tons.

Much of the fishing gear in use today is relatively unselective, catching many species in addition to the target fish. Fisheries conducted in a mixed-species area can only be properly managed if the ramifications of this by-catch are recognized. Regulations based on species catch quotas rarely do so, and significant overfishing is often the result. One reason for this is that yields of different species are maximized at different effort levels, and it is impossible to adjust the fishing effort to each level so as to maximize the sustainable yield of all. Thus, some populations will be overfished and some underfished, and the total potential yields will be smaller than those indicated by species assessments that ignore these mixed-fishery effects.

Let us now combine these effects with the cyclical population trends discussed earlier. The yellowtail flounder fishery of southern New England serves as a model. Although there is no record of the actual scope of natural fluctuations, the evidence illustrates a chronology something like that shown in Figure 5. The fishery, beginning at the time of a natural increase, tended to lower the maximum, accentuate the decline, and depress the minimum. During this period (1935-60), most of the effort in the area came from the flounder fleet. When economic returns from flounder fishing diminished, primarily because of reduced population size, effort was transferred to more lucrative species (sea scallop, for the most part). The reduced fishing mortality on flounder allowed the population to recover, but only to the point where it became economically attractive to resume fishing in earnest.

Meanwhile, other species of fish in the area have attracted other fleets whose by-catch has also increased flounder mortality. The result has been that the total flounder catch rose more rapidly than would otherwise have been the case, the period of maximum catches was shorter, and the decline, when the population cycle again turned downward, was more precipitous. Today even if fishermen interested primarily in yellowtail leave the fishing grounds because they think their absence will help the population to recover, the by-catch of flounder of other species-directed fisheries will prevent the normal, cyclical recovery or, at the very least, prolong the period of minimum population size. What, in reality, is the maximum sustainable yield of yellowtail? Certainly, the traditional methods of assessment are not applicable here.

The objectives of allocating catch to species-directed fisheries may only be met by taking a total yield considerably less than the calculated maximum. This is illustrated in Table 1 by data from the fisheries off New England. The by-catches of all species have been estimated for each of the directed fisheries. If an individual species (or group of species) is not to be overfished, the total harvest of that species cannot exceed the *maximum allowable catch*. The amount of catch of a species to be allowed the directed fisheries, taking into account the mortality generated as by-catch and maximizing total catch without overfishing any individual species (i.e., without exceeding any of the maximum average yields) is given as *directed catch quotas*. The result is the *total expected catch*. The obvious implication is that yield is maximized by concentrating fisheries on the large populations that have the smallest by-catch.

The procedures illustrated in Table 1 represent a solution based on the objectives of conservation. Social and other objectives, however, are frequently part of the pattern. For example, species-directed catches are often maintained for the benefit of local fishermen. These policy decisions require further adjustments in the interest

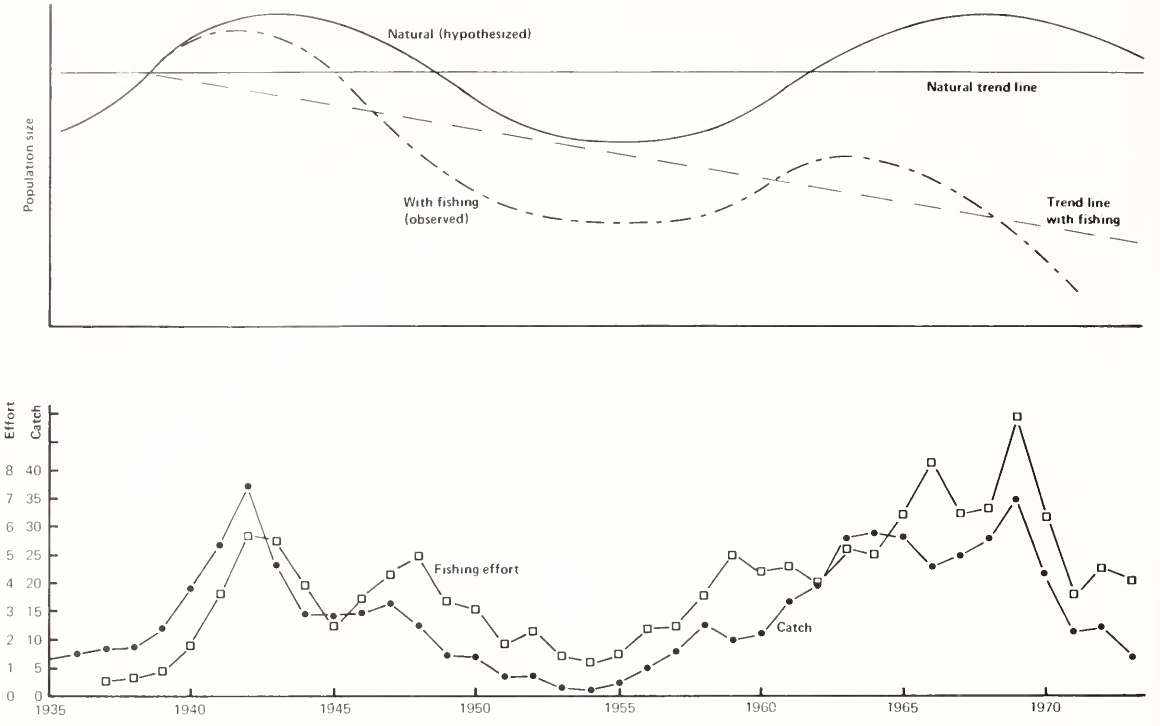

Figure 5. Trends in yellowtail flounder population size, catch, and fishing effort. Catch is in thousands of metric tons, effort in thousands of days fished.

Table 1

Calculation of expected catches off New England to maximize total yield when by-catch is included (in thousands of metric tons)

Directed fisheries	Maximum allowable catch	Directed catch quota	Total expected catch
Cod	45	32	40
Haddock	6	0	6
Redfish	25	23	25
Silver hake	175	153	168
Red hake	65	0	65
Pollock	27	22	27
Yellowtail flounder	21	9	21
Other flounder	25	12	25
Other groundfish	50	0	50
Herring	175	137	175
Mackerel	285	216	285
Other pelagics	7	2	7
Other fish	92	21	62
Shellfish (squid)	71	52	71
Total	1069	679	1027

of sound management, as shown in Table 2. Allowable catches must be reduced for other species whose harvest involves by-catch of the fish so selected, thereby reducing the total catch. The smaller the desired population relative to others in the area, and the greater the by-catch of the species in other fisheries, the greater the reduction in the total yield must be to accommodate such a directed fishery. The reductions run counter to the much discussed policy of full utilization. Yet they exist and must be reckoned with.

Preparing for Cutbacks

We have pointed out some of the difficulties in precisely determining the yield and in directing fishing operations toward that yield with any degree of precision. An optimist would set the error factor in either assessment or attainment at around 20 percent, but the realistic planner would be wise to allow for even greater tolerance. The loss of yield due to underestimation of the potential, and the ensuing difficulty of correcting harvests, are less serious than those resulting from an overestimation of the potential. In fact, increased profit is generally obtained by fishing at a rate lower than that corresponding to the maximum, so that it is also better business to undershoot than to overshoot the maximum yield.

Table 2

Calculation of expected catches off New England when including certain minimum quotas for coastal fisheries (in thousands of metric tons)

Species sought	Maximum allowable catch	Directed catch quota	Total expected catch
Cod	45	30	39
Haddock	6	0	6
Redfish	25	23	25
Silver hake	175	125	141
Red hake	65	0	54
Pollock	27	23	27
Yellowtail flounder	21	10	21
Other flounder	25	15	25
Other groundfish	50	0	16
Herring	175	139	175
Mackerel	285	226	285
Other pelagics	7	2	7
Other fish	92	3	69
Shellfish (squid)	71	57	71
Total	1069	653	961

Maximum directed quotas for coastal fisheries:

Cod	8
Haddock	0
Redfish	19
Silver hake	3
All flounder	25
Red hake, Pollock, Other groundfish	9
Herring	21
Mackerel, Other pelagics	9
Other fish	3
Squid	5

It must also be appreciated that national fisheries development requires lead time. In thinking now of the problem, we must anticipate the status of resource populations at least three years from now; solutions surely will not proceed faster than that. Vessels entering the Northwest Atlantic fisheries today were planned several years ago when assessments were available for only a few species and when it was hopefully assumed that increased yields could be obtained.

Our observations imply the probability that exploitation of existing fisheries is well beyond the point of merely constraining further development. Indeed, severe and disrupting cutbacks must be faced, particularly in heavily exploited areas, if the objective of maximizing yields is to be achieved. It is likely that the existing harvesting capacity is already equal to that which the fish population can support on a worldwide basis. In our opinion, only the most careful control of fishery exploitation will lead to further sustainable increases in the future.

But control and regulation of fisheries are not yet adequate to the task. Statistical reporting is inaccurate, particularly when it comes to accounting for the considerable amounts of fish that are caught and discarded at sea. Some elements of the fisheries, such as recreational fishing or parties not respecting agreements, are exempt from control. And enforcement methods are spotty and often criticized as being discriminatory.

The foregoing suggests several requirements for effective fisheries management: first, approximately real-time collection and processing of fishery statistics and biological survey data; second, adequate assessments of the productivity and potential yields of fish stocks; third, enforceable regulatory measures that relate as directly as possible to fishing effort; fourth, credible and even-handed enforcement procedures; fifth, a mechanism for the identification of common objectives and for allocating yield to users; and sixth, a real effort on the part of all involved in fisheries to understand the complexities of managing renewable natural resources. Both the biologist and the manager must strive harder to understand one another.

These requirements should be met simultaneously, since none is easier to satisfy than any other. It may well prove more expedient to deal with them on a regional basis. And it will be necessary along the way to solve difficult jurisdictional problems, such as those before the Law of the Sea Conference. But whatever the geopolitics, if the development of fishery policy does not include adequate provision for meeting all these requirements as a matter of first priority, an annual harvest of 100 million tons of fish will not be realized in the foreseeable future.

Robert Edwards is Director of the Northeast Fisheries Center, National Marine Fisheries Service, Woods Hole. Richard Hennemuth is Deputy Director.

Mariculture:
How Much Protein and For Whom?

John H. Ryther

Marine aquaculture, or mariculture, is generally looked upon in the Western World as a new concept in food production, an outgrowth of the traditional commercial fishing of natural stocks of marine organisms, a more sophisticated approach whereby fast-disappearing luxury seafoods may be mass produced in intensive culture systems analagous to the feedlot production of cattle or the factory-like modern poultry industry. Often overlooked is the fact that aquaculture, though usually carried out in fresh or estuarine waters, is an old and well-established practice in many parts of the undeveloped world, particularly in Southeast Asia and the Orient, where aquatic organisms have been successfully cultured for centuries. Although these latter practices are technologically unsophisticated, they are surprisingly reliable and productive, and have made a significant contribution, economically and nutritionally, to those parts of the world where they are carried out.

Such, unfortunately, cannot be said for the embryonic mariculture industry of the United States, the rather dismal track record of which threatens the field with extinction before it has fairly gotten under way. What are the reasons for these ill-fated beginnings, and what is the prognosis, here and elsewhere, for marine aquaculture? Before proceeding with such an analysis, let us look briefly at the current state-of-the-art. Who is growing what, where, and how? And even more basic, what kinds of animals can be grown in culture?

Desirable Characteristics in a Cultured Species

To be a suitable candidate for aquaculture, a species must satisfy several basic prerequisites. First, it must be a popular and preferably a luxury food, capable of bringing a high market price. Failing this characteristic, the species must be easy and inexpensive to grow so that, if marketed at a modest price, it can still insure a profit to the grower. It

Farmers in Thailand harvest some of the fish grown as a by-product of rice cultivation. (I. Polunin, Bruce Coleman Inc.)

must grow rather quickly in culture, if possible to a marketable size within a year or less. It must be hardy and adaptable to growth in rather dense culture with a minimum of mortality due to handling and crowding under the unnatural conditions of cultivation. It should be relatively resistant to the diseases and parasites that are normally present in seawater. Its nutritional requirements must be known, and it must be capable of feeding, with a high conversion efficiency (growth: food consumed), upon artificial or natural foods that are readily available and inexpensive. Finally, the species should be capable of being brought to sexual maturity and successfully mated and spawned in captivity—naturally or by artificial manipulation (hormone-induced maturation, stripping of eggs and sperm, etc.)—hatched, and reared through its larval stages to juvenile animals, again without excessive mortality.

The entire propagation and larval development process entails a completely different set of practices and procedures from those involved in "growing out" the juvenile animals to market-sized adults. Once the problems are solved, assuming that the established procedures are carefully and consistently followed, the rearing of animals to the juvenile stage usually becomes routine, and vast numbers can be produced on demand in modest facilities and at relatively low cost. But the biological problems of breeding and larval rearing are often subtle and intractable. As a result, many otherwise desirable species have not yet been grown in captivity throughout their complete life cycle; and post-larval, juvenile animals cannot be produced routinely, if at all. In some cases this problem has been circumvented by collecting juveniles from their natural nursery areas. Although this is typically done in the culture of some species (milkfish in Southeast Asia, yellowtail in Japan), the difficulty and expense of obtaining, on a reliable basis, a sufficient number of juveniles to support a sizable culture operation are constraints that have severely limited the development and expansion of such practices.

With the above, rather formidable list of prerequisites, it is perhaps not surprising that only a handful of marine and estuarine species have passed the test and are now in commercial culture. These are reviewed briefly below.

Molluscs

The bivalve molluscs represent a rather special case. Following the pioneer work of W. F. Wells of New York State during the 1920s and the subsequent efforts of V. L. Loosanoff (NMFS, Milford, Conn.) and T. Imai (Japan), first oysters and then many species of molluscs—including clams, scallops, and mussels—have been routinely spawned and reared through their larval stages to juvenile or "seed" shellfish in commercial hatcheries. (One of the few innovations in aquaculture that originated in the United States, shellfish hatcheries are now established around the world.) However, except for a few experimental attempts, no one has yet reared the newly set "seed" to market-sized adults in a controlled, artificial grow-out system, due largely to the difficulty and impracticality of producing a sufficient quantity of the unicellular algae or other microorganisms upon which the bivalves feed, or of finding a suitable artificial food. Instead, the hatchery-produced juveniles are grown to market size in natural environments (bays, estuaries, or protected coastal waters), on the bottom or sometimes in or on trays, racks, strings, or other devices to suspend them off the bottom. The role of the hatchery is thus to supplement or replace natural reproduction or to provide juvenile animals for stocking and colonizing new areas.

The cultivation of oysters and mussels is one of the world's oldest and, overall, probably the most successful form of mariculture. It ranges in complexity from the very simple practice of harvesting natural populations—actually a form of commercial fishing that can hardly justify the term "culture"—to the highly sophisticated and intensive raft culture of oysters in Japan and of mussels in Spain. Intermediate are those enterprises, notably in the United States and Europe, where seed shellfish—hatchery-reared or collected from nature by various means—are planted, tended, moved about, and otherwise cultivated in specially designated and usually privately controlled growing areas.

Whatever the culture method, the bivalves feed upon the plankton algae that are normally present in the seawater, and there is no attempt to control or improve upon the quality or rate of production of this natural food. Nevertheless, yields from shellfish culture may be impressive, ranging from 10 to over 1000 metric tons per acre per year of pure meat (shells excluded) in the more successful raft-culture practices. Such yields are made possible by the fact that food, in the form of suspended phytoplankton, produced over an area several orders of magnitude greater than that involved in the shellfish culture, is brought to the molluscs by the tides, currents, and other water movements; and the animals thus serve as a convenient and highly efficient concentrator and integrator, within a small area, of the organic

In raft culture, seed oysters attached to scallop or oyster shells are strung on wire or rope and suspended from rafts. (Top) Bamboo oyster rafts buoyed by hollow drums. (Bottom) Intensive oyster culture in Kesennuma Bay, Japan, where there are more than 5000 rafts. (J. H. Ryther, from J. E. Bardach, J. H. Ryther, and W. O. McLarney, Aquaculture, *Wiley, 1972)*

At the NMFS Experimental Shellfish Hatchery, Milford, Connecticut, clams and oysters are induced to spawn out of season (top); juvenile clams, in a controlled grow-out system, are fed cultured algae (center); and on the "tank farm," post-set oysters are grown out, and algae mass-cultured (bottom). (NMFS, Middle Atlantic Coastal Fisheries Center, Milford Laboratory, Milford, Conn.)

matter produced over a large region.

The only other mollusc that is a serious candidate for aquaculture is the abalone—highly prized, highly priced, and rapidly disappearing from natural fisheries throughout the world. Readily amenable to the same hatchery-rearing techniques as oysters and other bivalves, young abalone can be produced in very large numbers at low cost, but as many as five to seven years are required for the juveniles to reach a marketable size. They must somehow be provided throughout that period with a steady and rather large supply of the right kinds of seaweeds upon which they naturally feed. Thus, commercial abalone culture has been attempted but has yet to succeed beyond the practice, by government laboratories in Japan, of stocking "seed" animals in natural growing areas, much the same as is done with oysters and other bivalves in the United States.

The other major group of molluscs, squid and octopus have been grown experimentally in the Far East, where they are highly regarded; but, so far as is known, not on an established commercial basis.

Seaweeds

A practice somewhat analogous to mollusc culture is followed in Japan and perhaps a few other Far Eastern countries, where certain species of seaweeds are grown and marketed as a luxury food (nori, aonori, wakami). Many of these algae have complicated life cycles, with an alteration of generations involving two quite dissimilar life forms—the large conventional seaweed that is eaten, and a much smaller, near-microscopic form that produces the spores from which the seaweed grows.

The complete life cycle of some species of commercially important seaweeds has only recently been understood and described. There are now small culture facilities throughout Japan where the spore-producing plants are cultivated. Usually operated by the prefectural governments or fishery cooperatives, these laboratories maintain the algae until their spores are released, at which time the local growers, for a nominal fee, immerse into the culture system string-mesh nets, ropes, or other devices to which the spores attach. These are then planted out in estuaries or protected coastal areas, attached to wooden frames, hung from longlines, or otherwise suspended, where the spores then grow to the edible seaweed form.

Crustaceans

Among the crustaceans, indeed of all marine organisms, the penaeid shrimp (or prawns) are the

most popular target for aquaculture, due in large part to their universal popularity, high price, and almost unlimited market potential. The initial breakthrough in shrimp culture was achieved in 1934 by the Japanese fishery biologist Motosaku Fujinaga, when he successfully spawned and hatched the eggs of *Penaeus japonicus* ("kuruma" shrimp in Japan) from gravid females and reared the larvae through their several stages to juvenile shrimp. As mentioned above, once this stage was accomplished and perfected, the hatchery production of post-larval shrimp soon became routine and is now widely practiced in commercial, government, and academic institutions throughout the world. All of the popular food species from the Southeastern and Gulf coasts of the United States (pink, white, and brown shrimp) are now hatchery-reared in various U.S. aquaculture facilities, and other possibly better-suited species from elsewhere in the world are being tested.

The one phase of the life cycle of shrimp that has thus far eluded hatchery manipulation, at least as an established practice, is the bringing of adult shrimp to sexual maturity, egg production, and mating in captivity. Gravid, fertilized females must still be obtained from the commercial fishery and brought into the hatchery, where spawning and hatching may then be readily induced, almost on demand. This limitation may represent a rather serious constraint to a large aquaculture operation, particularly if a year-round commercial shrimp fishery is not operative near the hatchery. The post-larval shrimp may be grown to adults in a number of ways: in ponds, cement raceways, fenced-off portions of embayments, etc. One of the most attractive attributes of shrimp is their ability to reach a marketable size in as little as four to six months, given proper and adequate food and optimal temperatures, salinity, and other environmental conditions. Two and even three crops a year can, at least theoretically, be grown in some parts of the world.

Modern shrimp farming usually involves growing the animals in dense culture, stocking up to 100,000 post-larvae, with projected yields of 10 tons or more per acre. Shrimp are omnivores and eat a wide variety of living and dead plant and animal material; but no natural system can provide the food for such densities, and they must therefore be fed extraneously. In Japan a variety of natural foods are used: ground whole fish, molluscs, even shrimp taken in the commercial fishery but too small

Scallop shells are used to collect "spat" in a seed oyster farm in northeast Japan. The free-swimming larvae metamorphose, settle on a solid object, such as a shell, and remain sessile for the rest of their lives. (J. H. Ryther, from J. E. Bardach, J. H. Ryther, and W. O. McLarney, Aquaculture, *Wiley, 1972)*

for the market. The high price of this food and of the associated labor and other operating costs is at least partly compensated by the fact that prime kuruma shrimp, marketed alive for the tempura restaurant trade, brings as much as $10/lb to the grower. In the United States, where seafood prices have not yet reached this level, such costs would be prohibitive, and emphasis has been placed on the development of inexpensive artificial feeds and more mechanization of the culture operation, thus far without significant commercial success.

The other marine crustacean that has long been eyed by aquacultural entrepreneurs as a species of enormous market potential and very high value is the American lobster (*Homarus americanus*). Unlike shrimp, lobsters are rather easily carried through their complete life cycle in captivity, eliminating dependence upon egg-bearing females obtained from the commercial fishery.

In their natural environment of Eastern Canadian and New England coastal waters, lobsters require five to seven years to reach a marketable and legal size of about one pound, but they will attain the same growth in culture in two years or less if maintained at their optimum temperature of about 20°C.

Lobsters, however, are cannibalistic by nature, and freshly molted individuals fall prey to their own species if they are not physically protected from one another. They are territorial by nature and do not readily adapt to the crowded conditions that many other species accept in culture. And a successful artificial feed has yet to be developed. Although these problems are not insurmountable, the economics of growing, feeding, and caring for large numbers of individually compartmentalized lobsters and of maintaining them at their optimal temperature for as long as two years has thus far discouraged potential culturists from any serious commercial venture with the species.

The clawless cousin of the American lobster, the spiny lobster (sometimes also called crayfish, but not to be confused with the small, freshwater crustacean) includes many tropical and semitropical species that range throughout the world. Although they are also valuable food species, none has yet been reared through its long and complicated larval development. There has been speculation on the possibility of collecting young spiny lobsters from the wild and growing them to market size in captivity; but they are not abundant or particularly easy to catch in quantity, and the matter has not been pursued.

Shrimp farming facilities in Takamatsu, Japan. (Top) Tanks for rearing larvae. Each 250-gallon tank, heated and filled with filtered seawater and air, can accommodate 15,000 larvae. The building has a greenhouse roof. (Bottom) Cement raceways in which post-larval shrimp are grown to adults. Seawater is pumped through each 10-by-100-meter raceway. (J. H. Ryther, from J. E. Bardach, J. H. Ryther, and W. O. McLarney, Aquaculture, *Wiley, 1972)*

Finfishes

The other major group of cultivated marine organisms is the finfishes. This includes a somewhat greater variety but still a surprisingly small number of species. Of these, the salmonid fishes (trout and salmon) are the most popular and widespread in their use, with almost universal acceptance as a luxury food. These are anadromous species that spawn and spend the first part of their lives in freshwater, where they can also remain and grow to maturity.

Freshwater trout culture is among the oldest and most highly developed forms of aquaculture in the Western World, originally carried out for the purpose of stocking natural waters for sports fishing. Only recently have these species been grown directly for human food. After some initial growth in freshwater, most trout can be readily acclimated to salt water, though not all are anadromous in nature. Rainbow trout in particular

have proved a successful species for mariculture in such widespread countries as Japan, New Zealand, Scotland, Norway, Denmark, United States, and Canada. More recently, both Atlantic and Pacific species of salmon have become popular substitutes for trout, having much the same requirements and characteristics in culture, but commanding a significantly higher price on the market.

Because of the long history of salmonid culture, controlled spawning, larval rearing, and juvenile development (all in freshwater) have become commonplace. Grow-out to whatever size is desired for market (half-pound to one-pound "pan size" salmon is an interesting new product in this field) is also not difficult, though disease is a persistent problem with these species. A variety of pelletized, artificial feeds are commercially available and used with varying but generally good success.

Salmonids are active fishes with a high metabolism and, in dense culture, require a rapid exchange of water for oxygen replenishment and waste removal. Culture systems include raceways, ponds, impoundments of various sizes and shapes, and net cages, which may be suspended in protected inshore waters. The latter have the advantage that natural currents and tidal action provide the water exchange without the need for costly pumping, a benefit that may, however, be offset by the vulnerability of such structures to weather, tides, predators, and other factors and by their relative inaccessibility to feeding and maintenance.

In short, the biology and technology of salmonid fish culture, though not without some remaining, persistent problems, are well developed; it is primarily the economic factors that decide the success or failure of a mariculture operation. Such is not the case with other, truly marine species of finfishes, most of which have never been successfully cultured anywhere and none of which are now commercially reared in the United States. The one local species that has come closest to utilization is the pompano, a tropical to semitropical fish highly regarded in selected areas of the Southern United States, where it is commercially landed, and probably with considerable, if limited, potential for an expanded market. Pompano, like many marine fishes, have small and delicate eggs and larvae that are sensitive and difficult to handle, feed, and grow. Until very recently, the species has resisted attempts at their artificial spawning and larval rearing; and pompano culture efforts, centered in Southern Florida, were dependent upon collecting wild fry from along that coastline, a practice that could not sustain any substantial culture operation. One company has now made the critical breakthroughs and can routinely produce juvenile pompano on demand from its own brood stock, providing not only independence from the wild stock but also the means for genetic selection and improvement of the species specifically for characteristics desirable for culture. Commercial pompano culture is therefore now a distinct possibility, but not yet economically a reality.

*(Top) Egg-bearing female American lobster (*Homerus americanus*). (Bottom) Third-stage American lobster larvae, about eight days old. (Gareth W. Coffin, NMFS, Biological Laboratory, Boothbay Harbor, Me.)*

Only in Japan, where a variety of marine life is avidly consumed, has mariculture developed to the stage where several species of finfishes are commercially grown. Most of these, however, are freshwater species, as is true elsewhere in the world. The list of cultured marine fishes is still short, but includes, in addition to the ubiquitous salmonids, yellowtail (a scombroid fish related to the amberjack), puffers (a great delicacy in Japan), both black and red porgies, and a few others including tuna, now being reared experimentally.

Yellowtail has not yet been propagated in captivity, but a separate and carefully controlled industry exists for the collection of fry from the wild and their rearing to juvenile fish ready for stocking in the net cages that had their origin and have been very successfully employed in this form of mariculture. Both fry and adults are fed ground waste fish, shrimp, and other natural seafoods, but increasing use is now being made of artificial feeds.

Although highly labor intensive and costly (a factor again offset by the high price of luxury seafoods in Japan), yellowtail culture must be considered one of the most successful examples of intensive mariculture in the world today. Carefully regulated and supervised, the industry produced over 30,000 metric tons of fish in 1968, and only restrictions on the numbers of fry allowed to be taken from the wild stock has prevented much greater production. Significant expansion of the industry will undoubtedly occur when and if controlled reproduction of the species is achieved.

Fish Farming

Thus far, only high-priced, luxury seafoods have been discussed here—species grown for the most part in the wealthier, developed countries of the world where profit is the only motive for aquaculture. The contribution of such culture to the particular country's food supply is incidental and almost negligible, besides being well beyond the economic reach of any inhabitants who may suffer from protein deficiency. This, however, is not the case everywhere. As mentioned earlier, fish farming has been successfully practiced for centuries in parts of Southeast Asia and the Far East, particularly Mainland China. Most of this kind of aquaculture is done in freshwater ponds, but there are also some marine species that are widely used in estuarine, brackish-water culture. They include the mullets, of which there are several species, and the milkfish, both of which are distributed throughout the world's tropical and semitropical latitudes.

Both mullet and milkfish are extremely hardy and adaptable fishes that can tolerate, among other things, salinities ranging from pure freshwater to full seawater. They are popular food fish in most places where they naturally occur or are grown. Most important, they are among the few edible finfishes that are predominantly herbivorous, or omnivorous, feeding largely on filamentous algae, dead organic matter, and the many small animals that live associated with the mats of algal material in brackish ponds and estuaries.

Recent advances in Israel, Taiwan, Hawaii, and elsewhere have now made it possible to bring mullet to sexual maturity and to spawn them artificially, through use of pituitary hormone injection, though this is not yet standard practice in mullet culture. Artificial propagation has not yet been accomplished with milkfish, and it is suspected that the species is not normally grown in captivity to the size and age at which it normally matures sexually. At present, the fry of both species are collected from natural nursery areas and, as with Japanese yellowtail culture, there is often a separate industry involving their collection and cultivation to juveniles ready for stocking in grow-out ponds.

Probably more mullet are reared in fresh than in salt water, but significant quantities of mullet and most milkfish are grown in shallow marine to brackish-water ponds, usually constructed from coastal mangrove swamps. Because of their low position on the food chain, these fish do not need to be fed extraneously with natural or prepared feeds, but simply forage on the natural algal populations and the associated living and dead flora and fauna. The mats of filamentous algae, which are called "lab-lab" in the Philippines, are often specially prepared and cultivated in the ponds by various, rather simple methods; and they may be encouraged by modest fertilization, usually with green manure. But one of their principal constituents are filamentous blue-green algae, which have the ability to fix atmospheric nitrogen and thereby reduce or eliminate the need for providing that scarce and costly ingredient.

Because there is no extraneous feeding and, for that and other reasons, very little labor required in this kind of aquaculture (except for stocking and harvesting, a single watchman is the sole requirement for maintaining several hundred acres of ponds), operating costs are very low. Yields also are low relative to those that may be obtained under the best of conditions in intensive raceway, pond, or cage culture with heavy feeding; but one-half-pound milkfish can be grown in about six months, and yields on the order of one metric ton

Aerial view of brackish-water milkfish ponds in the Philippines. White structures are sluice gates; bamboo screens filter the water entering the ponds from the estuary. (P. Boonserm, FAO)

per acre per year are common, a production that is impressive by any standard for high-quality animal protein.

Thousands of acres of brackish-water milkfish ponds have been constructed from the mangrove-lined coasts of Taiwan, Hong Kong, Philippines, Malaysia, Indonesia, and neighboring countries. Together, their annual yield is in excess of a quarter of a million metric tons of this popular food fish. Equally important, because of the simplicity and low operating costs of the culture method, the fish may be marketed at profit at a relatively low price that is within reach of the average consumer of those countries.

Problems with Intensive Mariculture

With the above background, let us now return to the status of modern intensive marine aquaculture, as typified by the general approach that has been taken in the United States, and consider some of the problems that have beset this new field. Much of the difficulty must be attributed to the ambition, impatience, and naïveté of the aquacultural entrepreneur. The cliché of learning to walk before trying to run is nowhere more appropriate, but venture capital is not often available for small pilot projects, or slow, deliberate progress. The experience of rearing dozens to hundreds of animals in the laboratory, at the level of a basic research project, is too often extrapolated to a large commercial operation involving millions of animals, in almost complete ignorance of the biological, technical, and economic problems of scaling.

Coastal wetlands are becoming scarce and costly. Often they are unavailable in large tracts, or their use is severely restricted. It has been well

documented that many species of fish can not only live but also grow normally when packed together literally like sardines in a can, if enough food and water are pumped through the container. So the temptation is strong to emulate the cattle feedlot system: condense the aquaculture operation into a small and manageable fish factory rather than turn the animals loose in extensive and expensive grazing areas, and let technology provide for their care and feeding.

The ecological problems encountered in such highly intensified mariculture may be formidable. Disease, always the nemesis of animal breeders, is a far greater problem in the aquatic medium where, in contrast to terrestrial situations, the spread of pathogens from infected to uninfected individuals is virtually impossible to prevent. The incidence and spread of disease is directly proportional to the density of the animals, not so much because their proximity facilitates transmission but, probably more important, because crowded animals are frequently, if not always, in a condition of physiological stress, which makes them particularly vulnerable to the onset and effects of diseases. In addition to the usual bacterial and viral infections to which aquatic animals are subject, various parasites are also readily transmitted in the aquatic medium and may seriously affect survival, growth, and condition as well as the appearance and marketability of the product.

Aquaculturists sometimes claim conversion efficiencies approaching 1:1—that is, one pound of food is required to produce a pound of the cultured animal. This is an apparent ecological impossibility, among other things defying the second law of thermodynamics, but results from the fact that, under the best of conditions, one pound of essentially dry food can be converted to a pound, fresh weight, of fish that consists of some 80 percent water—an actual efficiency of about 20 percent. In practice, this is seldom if ever achieved; efficiencies of 10 percent or much less are the rule. Thus, the grow-out of a million pounds of fish in a year or less requires an input of between one and ten million pounds of food, most of which either is not eaten in the first place or is defecated or excreted back into the system as both dissolved and particulate wastes. The organic content of these wastes has an exceedingly high oxygen demand, particularly at the relatively high water temperatures (15-25°C) usually preferred by culturists for rapid growth. Some of the wastes, such as ammonia and its intermediate oxidized form, nitrite, are highly toxic. Finally, the organic wastes provide an ideal substrate for disease organisms and exacerbate that problem.

For all of the above reasons, the wastes and uneaten food must be quickly and efficiently removed from the culture system. Rapid water exchange, with retention times of minutes to a few hours at most are essential in dense culture systems. Solid wastes that do not flush out with the normal flow of water must be removed by mechanical means or, often, by hand labor. Even the most ingenious self-cleaning techniques usually cannot prevent the growth of fouling organisms—bacterial slimes, algae, various invertebrate species—on the bottoms and sides of the culture system. Thus, no matter how efficient and effective the mechanization, considerable hand labor appears to be an inescapable requirement.

Flushing of the wastes from an intensive aquaculture system simply transfers them elsewhere in the environment. Aquaculture is therefore a significant source of pollution. It has been estimated that the wastes of about 10 pounds of hatchery-reared trout are equivalent to those of one human. A million-pound culture facility produces the same kinds and quantities of wastewater as a city of roughly 100,000 people. Discharge of such wastes into estuaries or coastal waters is not only undesirable but, under present regulations, illegal without the same degree of treatment as required for domestic human wastewater.

Economically, the problems of intensive mariculture are no brighter. The equipment and machinery for handling or even for occupying large volumes of seawater with adequate protection and minimum risks from corrosion, fouling, weather, etc., are extremely costly. Capital outlay for a major mariculture facility, whatever the configuration or method of culture, can easily run to millions of dollars. Operating costs, particularly where pumping large volumes of water is involved, but also including the inevitable labor requirements, are also high.

But the single greatest cost of intensive mariculture is usually that of food. Typically, the prepared pelletized feeds now in use consist of mixtures of animal and vegetable meals and oils, fortified with mineral and vitamin supplements. Requiring a high and complete protein content for rapid growth, such feeds usually contain a significant proportion, as much as 25 to 50 percent of fish meal.

Commercial feeds generally range from one to ten cents per pound. At low conversion efficiencies, of the order of 10:1 at the high end of the price spectrum, the culturist has an investment in food alone of about $1.00 per pound of his

product—an uneconomical practice at the outset. Commercial culturists can and must do much better than this, but food still normally accounts for 25-50 percent of total operating costs. And, while the price of luxury seafoods is rapidly escalating, the cost of feed may be climbing even more rapidly. The recent failure of the Peruvian anchoveta fishery, the major source of fish meal in the world, more than doubled the cost of that commodity during 1971-72, leaving the aquaculturist with the dilemma of absorbing the increase in his already prohibitive operating costs or going to less desirable food ingredients that result in poorer growth and lower conversion efficiencies.

Finally, the provisions of the new Federal Clean Water Act and Amendments, forcing the mariculture industry to subject its effluents to sophisticated wastewater treatment, if enforced, will provide a new cost factor that could bankrupt the few marginally successful mariculture enterprises now operating in the United States.

General Prognosis

It seems likely that "feedlot" production of marine fishes and invertebrates, on a commercially sound basis, will prove successful for at least some species. In my opinion, this will not happen quickly, and some new developments and breakthroughs, of both an engineering and a biological nature, may well be required before reliable and profitable mariculture of this kind will take hold. The danger is that repeated large-scale failures (the consistent pattern for the past decade) will discourage further investment of money and scientific effort in the field. It is to be hoped that such organizations as the National Sea Grant Program will continue to fill the gap between the laboratory experimenters and the large-scale entrepreneurs with support of some much-needed pilot-scale research, large enough in magnitude to reveal and address the problems of mariculture on a commercial scale.

But, aquaculture, freshwater or marine, that requires intensive artificial feeding and a high level of mechanization and/or labor cannot help alleviate the world food problem or even local shortages of animal protein. For such practices, like cattle feedlots, are food-consuming rather than food-producing systems; and the luxury crops they do produce, however successfully, are well beyond both the economic and the nutritional means of the people that most need a new, inexpensive source of protein.

Not so the extensive estuarine fish-pond farming of Southeast Asia, where mullet, milkfish, shrimp, and a few other species are grown on natural food. Requiring a minimum of labor and other operating costs and low capitalization, these practices can and do successfully produce significant quantities of high-quality and relatively low-priced animal protein. The same is true of bivalve mollusc culture, the only other form of mariculture that is an established and economically viable practice almost worldwide. Shellfish culture is more "intensive" than fish-pond culture, with respect to spatial requirements and the density of the cultured animals, because the molluscs concentrate the natural food produced over a much larger area and brought to them by water movement; but the principle is the same. No artificial external feeding is required, and the attendant problems and costs described above are avoided.

The major constraint to these forms of mariculture has been the limited supply and relatively high cost of juvenile animals obtained from the natural nursery areas. Instead of food and labor, it is the young animals that represent the single greatest cost to the fish farmer. Here is where modern technology could make an important contribution. It was noted above that mullet, shrimp, and many species of molluscs can now be artificially propagated in hatcheries. There appears to be no reason why milkfish would not eventually yield to such manipulation or, failing that, could not be replaced by other species that can be so reared. The point was also made that once the problems of artificial propagation are solved, the hatchery production of vast numbers of juveniles usually becomes routine and surprisingly inexpensive, and does not require large or expensive facilities. The establishment of hatcheries and the training of personnel to operate them could therefore provide a valuable stimulant to the expansion of what is already an established and successful form of mariculture.

The other constraints to the further development of estuarine pond culture in the developing countries are largely of a social-political-economic nature and involve providing access to coastal wetlands, low-interest loans, and other incentives to potential mariculturists. Perhaps educational programs, coupled with such technological advances as the hatcheries discussed above, would bring about a climate conducive to significant expansion of the industry.

What is the potential of coastal fish farming? How much can this already impressive industry be expanded? In the Philippines, where 380,000 acres of milkfish ponds were in operation in 1970, another 1,200,000 acres of undeveloped

A typical tambak, or brackish-water fish pond, in Indonesia. High yields of fish protein are achieved in these areas. (FAO)

mangrove swamps have been designated as available for such purposes. In Indonesia alone, according to FAO estimates, there are some 15 million acres of coastal wetlands that could be converted to fish ponds. At the present best annual yields of one metric ton per acre, fish farming in these designated areas alone could supply the protein requirement of these countries.

There are on the order of one billion acres of coastal wetlands in the world, mostly mangrove swamps in the tropics. These areas are ecologically and esthetically valuable, and no one would like to see a major portion of such resources sacrificed to food production. (It is interesting, however, that man is not nearly so reluctant to use all that remains of his natural terrestrial environment for agriculture and livestock grazing–an area already comprising 8 billion acres, or about 25 percent of the Earth's land surface.) Nevertheless, the use of only 10 percent of these wetlands, 100 million acres, could result in the production of 100 million metric tons of fish, using only the simple, unsophisticated techniques now commonly practiced in Southeast Asia.

The annual landings from commercial fishing for the entire world are only about 70 million metric tons today, and various estimates have placed the potential sustained annual yield at figures as low as 100 million tons. A substantial fraction of these landings represent "commercial" species used only for fish meal and only indirectly consumed by man. Because of that and the inevitable waste involved in processing, transporting, and marketing fish caught long distances from their ultimate utilization (i.e., about half of the weight of most edible fishes is, at best, the edible portion), only about 17 percent of the total tonnage of commercial fish landings is actually consumed directly by man.

Fish grown in estuarine farm ponds, on the other hand, may be cultivated over extensive coastal areas where they may be marketed locally, often consumed by the grower as a form of subsistence farming, and as much as 50 percent of the total production may end up as human food.

The above projections, it should be remembered, are based on the better present-day yields of fish farming in Southeast Asia. It should eventually be possible, by application of appropriate management techniques now being developed for modern aquaculture, to increase these yields as much as tenfold, still using the same basic methods of extensive aquaculture with no extraneous feeding. Controlled fertilization of ponds to increase their basic productivity and provide more natural food to the cultured species is an established practice, first developed for freshwater farm ponds in the Southeastern United States. The cost of fertilization can be greatly decreased by recycling domestic and agricultural wastes, making such improvements economically feasible. Genetic improvement of stocks, control of diseases and parasites, elimination of predators and competitors, population management of the cultivated species to maintain maximum carrying capacity in the ponds, improved pond design and harvesting methods; these and other promising new developments can significantly increase yields.

In short, combining the best features of modern intensive mariculture with the traditional, established fish farming practices of Southeast Asia could very well place aquaculture in a significant position in world food production. In that event, 100 million acres or more of coastal wetlands may represent a potential resource that can hardly be ignored.

The real potential of mariculture thus lies not in placing oysters, salmon, or shrimp on the plates of an affluent and already overfed society, but in providing substantial amounts of low-cost and high-quality animal protein to those people who have the nutritional need and the available land but who require only social and technological assistance to realize the food-producing potential of their coastal wetlands.

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Trends in World Fisheries

Nets drying on bamboo frames, Martinique. (H. Monjaud, FAO)

M. A. Robinson and Adele Crispoldi

The mid-1970s is, at first glance, not a particularly propitious time to be analyzing trends in world fisheries. Recently a number of well-established trends have been reversed, or at least have changed course dramatically. These include the most basic series of all: the steady growth in the world catch, which had previously increased uninterruptedly from 1946 to 1968, but which fell in 1969 and again in 1972. Similarly, and in response, the volume of world trade in fishery commodities, which had also risen without interruption since the end of the Second World War, fell in 1969 and again in 1973, while prices on world markets for a number of important fishery commodities have fallen recently, some for the first time in many years. The presently depressed market for shrimp is in fact the first major setback experienced since this commodity became an important item of international trade.

Changes in the world catch of fish have in recent years been strongly influenced by the catches of shoaling pelagic species such as anchovy and sardine, substantial quantities of which are used for reduction to fish meal and oil. It is these species that gave much of the impetus to the growth in world production during the 1960s, and failure in certain of these fisheries in the present decade has been mainly responsible for that recent lack of growth. Nevertheless, at the same time as these changes have been occurring, other less spectacular

trends have been maintained. These trends can, with some confidence, be extrapolated into the future and can be expected to continue to exercise an influence on world fisheries development.

Among these trends, the most important is the continued increase in the production of fish for direct human consumption, which has been growing for the past 20 years at an average rate of 4 percent each year, or twice as fast as the growth rate of world population. World average consumption of fish is presently of the order of 12 kg per caput; at this level it accounts for roughly 4 percent of total protein supplies and 14 percent of supplies of protein from animal sources. This average, however, conceals very wide variations in the importance of fish in national diets. In some landlocked countries with natural environments unsuitable for the development of inland fisheries, fish consumption is almost negligible—less than 1 kg per caput per year. In other countries, such as the People's Republic of the Congo, the Republic of Vietnam, Japan, Indonesia, and the Philippines, fish consumption exceeds that of meat and accounts for as much as 60 percent of the animal protein intake.

Approximately 75 percent of the world catch of 65 million tons in 1973 was used for direct human consumption; of the balance some 14 million tons was reduced to meal and oil, and probably about a million tons was used for pet food, mink feed, fertilizer, and other miscellaneous purpose. Figure 1 indicates the distribution of that part of the world catch being used for direct human consumption, compared with the distribution of world population.

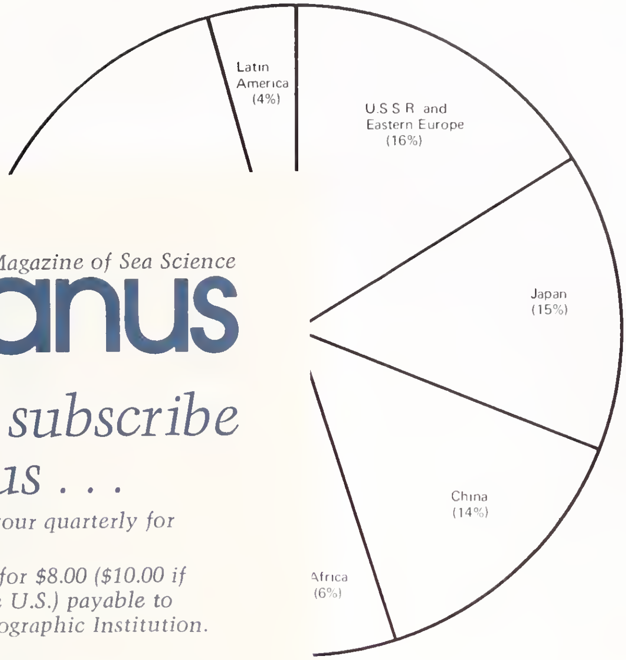
Fish meal has been excluded from the calculations on which the charts are based, since there are methodological problems involved in accounting for the nutritional value of fish entering human consumption after first being fed to livestock. Most fish meal is consumed in the high-income countries, and if the total quantities of fish used for reduction to fish meal are simply added to the fish consumed directly in these countries, then this brings the proportion of the world catch used by these countries to 50 percent, although they comprise no more than 20 percent of the world population. By contrast, the developing countries, which contain about 50 percent of the world population, presently consume no more than 25 percent of world fish supplies. The remaining 25 percent of current world fish supplies is consumed by the Socialist countries, which include, in addition to China, such important fishing nations as the U.S.S.R. and Poland.

Because of their larger and more rapidly increasing populations, the greater part of the future increase in demand will come from developing countries, and in particular, those where fish is a traditional item of consumption. Ninety percent of the increase in world population by the end of the century is expected to occur in developing countries, and on the basis of the U.N. medium variant, the population of Asia alone is expected almost to double by the year 2000 from its present level of just over 1.8 billion to 3.5 billion. Fish is a traditional item of consumption in many of the countries of Asia and makes a valuable contribution in protein to diets that, because of their heavy dependence on rice, have a rather unfavorable calorie:protein ratio. Average per caput consumption is in the region of 8.5 kg, and even to maintain this unchanged will require an additional 9 million tons by the end of the century.

In addition to the population effect, some increase in demand can be expected from the growth in per caput income, as well as redistribution to the poorer sections of the community—this latter effect is particularly important since at lower levels of income, changes in per caput income can have a marked effect on food consumption. This influence is, of course, reinforced where development by improving communications and the economic infrastructure generally makes fish more widely available. By contrast, in the high-income/high-consumption countries of North America and the European Economic Community, the level of fish consumption has remained rather stable for many years, and in any event is relatively insensitive to changes in income (although the commodity composition may alter). In these countries total demand is likely to grow rather slowly in line with the slow growth in population.

Other factors such as changes in relative prices will, of course, affect the demand for fish as for other foods, but over a span as long as ten or twenty years (which is about as long a period as it is possible to make meaningful forecasts), changes in population and income will be the main factors influencing the level of total demand. On the basis of present trends in both of these influences, and assuming that roughly 20 million tons of fish (the pre-Peruvian crisis level) continue to be used for reduction to fish meal, the total demand for fish would be of the order of 89 million tons by 1985 and 127 million tons by the end of the century. Variations around this figure depend, because of its dominant influence, largely on what assumptions are made about changes in the rate of population growth. There is at present some indication that fertility in the developing countries is declining,

WORLD FOOD FISH CONSUMPTION



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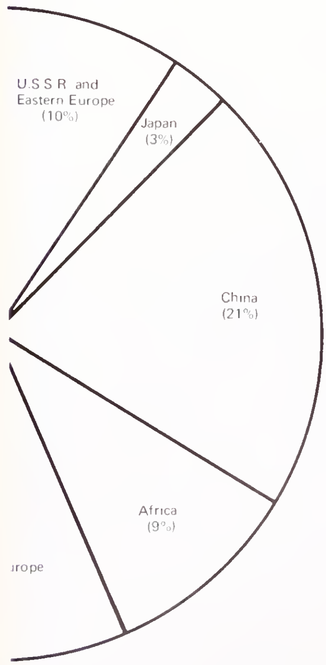

Figure 1. Distribution of world fish consumption and world population, 1970. Variations in the pattern of fish consumption are due largely to differences in per caput income. The relative importance of fish in the diet is mainly cultural. Thus, in countries at such diverse stages of development as the People's Democratic Republic of Yemen, Japan, Jamaica, and Iceland, fish has a prominent place in the diet compared with other sources of protein. However, the very highest levels of per caput consumption are found in high-income countries such as Iceland, Norway, Japan, and Portugal. The regional imbalance between population and fish consumption is unlikely to alter significantly in the foreseeable future, for although the developing countries' share of fish consumption will grow, so will their share of population.

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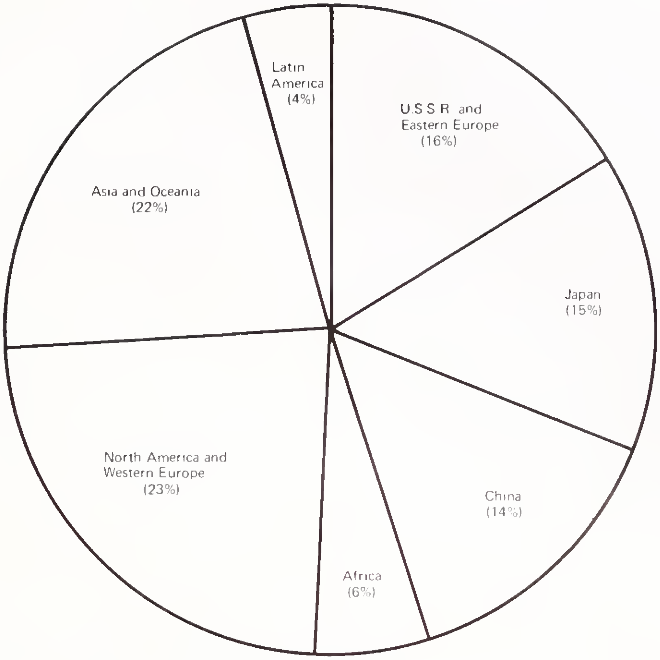
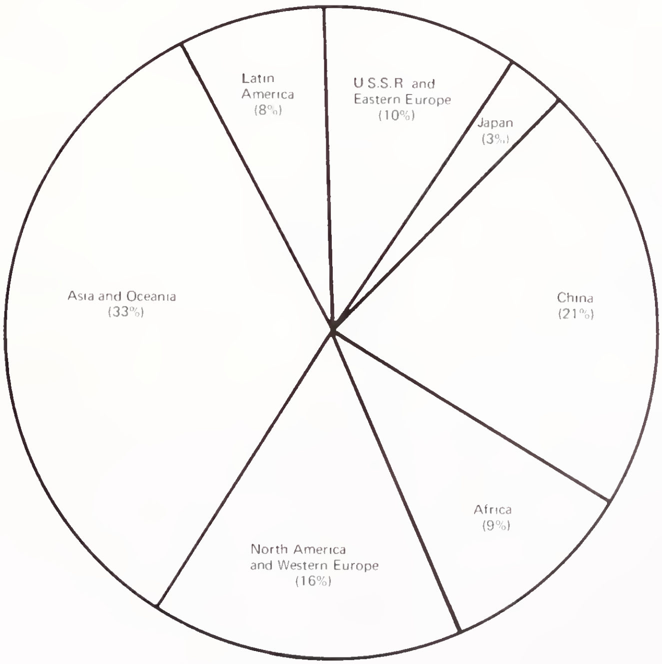


WORLD POPULATION



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and consequently demand may be rather lower than these levels. But even on the most minimum realistic assumptions, it is clear that the demand for fish will, before the end of the century, be pressing hard on the resource potential.

The most recent estimates indicate that the world's resources of marine fish, crustaceans, and molluscs are potentially capable of sustaining an annual catch of 118 million tons. About half of this potential is currently being exploited—although the degree of exploitation varies from area to area and also from species to species (see Figure 2). The waters of northern temperate latitudes are rather heavily fished, and much of the remaining potential from which future increases in the world catch will come lie in tropical and southern temperate latitudes—in particular the Southwest Atlantic, the Northwest Indian Ocean, and the Western Central Pacific. Some of the stocks in these areas, e.g., those within the Indonesian Archipelago, have remained lightly exploited, as they are too scattered and mixed to be of interest to large, long-range vessels but are beyond the range and technical capacity of the traditional local vessels. Other stocks, such as those in the Northwest Indian Ocean or the Southwest Atlantic, have so far not attracted much attention on account of their distances from the main centers of consumption, and because for this reason or others (e.g., the burden of license fees permitting fishing within exclusive fishing zones) the cost of their harvesting has deterred the long-range fleets of non-coastal states. But with the growing market opportunities being generated by population increase and rising income levels, these stocks are unlikely to remain much longer so lightly exploited.

To the potential from marine sources should be added an estimate for the probable

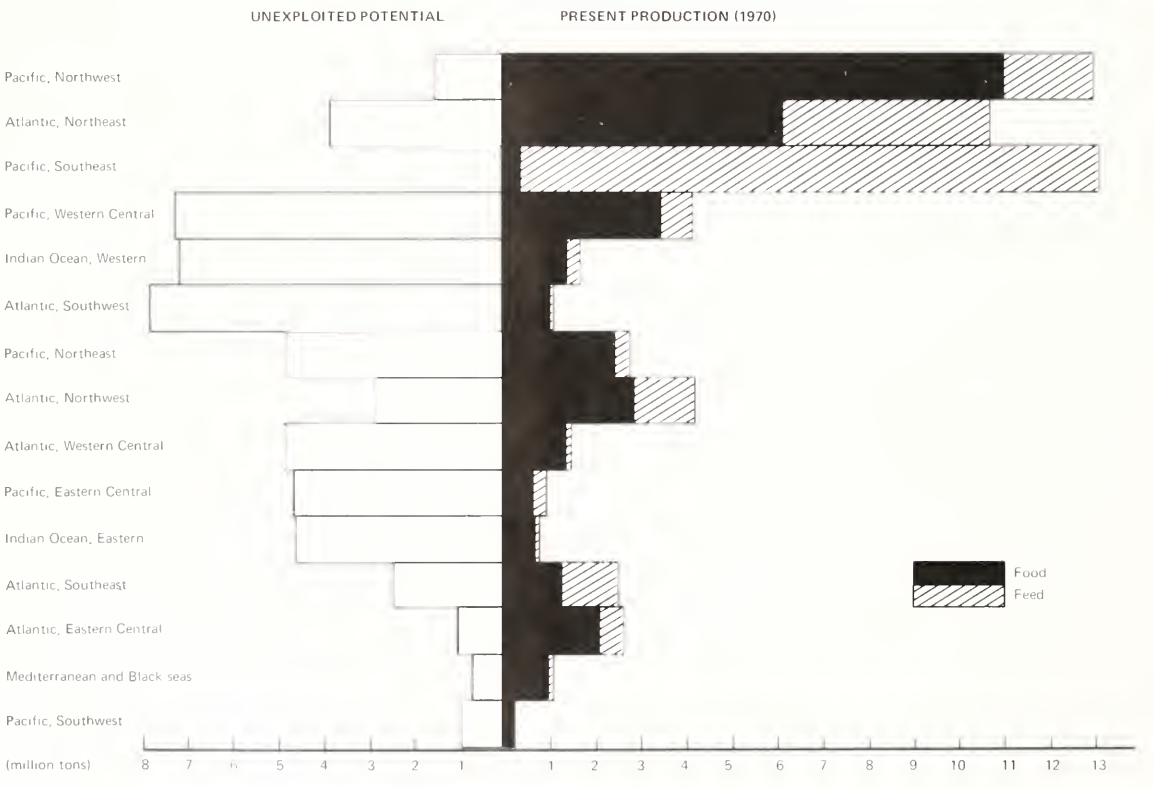

Figure 2. Production and potential of the world's oceans, 1970. Some 60 percent of the world catch of marine fish came from three areas: the Northwest Pacific, heavily exploited by the U.S.S.R. and Japan; the Northeast Atlantic, which lies in close proximity to the industrialized countries of Northwest Europe; and the Southeast Pacific, in terms of harvested potential the most heavily exploited area of all, and dominated by the anchoveta fishery. The areas of greatest unexploited potential lie in tropical or southern temperature latitudes, but none of them on present evidence have the productive capacity of the presently heavily exploited areas. The chart is based on physical quantities, but in terms of value the Mediterranean Sea and the West Indian Ocean assume much greater importance, although the Northwest Pacific still holds first place.

production from freshwater sources and from culture of all kinds. Present production from these sources amounts to about 10 million tons. The possibilities of increased catches from freshwaters are on a world scale limited but locally important, particularly in the flood plain fisheries and lakes of Africa and in Latin America. If these resources are to yield their full potential, then careful attention will have to be given to rational use of the water resources among competing ends, such as irrigation and power generation.

The potential from fish culture is technically very large but is constrained by economic factors—more precisely the cost of inputs compared with the price that can be obtained for the output. In this connection, reduction in the cost of inputs and improvements in the efficiency of the operation hold out the best possibilities for increased output, but the supply of fish from this source is also likely to be encouraged by the rising price of the more familiar wild species that will occur as demand increases and supply becomes increasingly inelastic, and to this extent the world fishery economy has a built-in adjustment mechanism. However, it is clear that the situation which has prevailed until comparatively recently, in which it was possible as one natural source of supply became exhausted to move to another, is rapidly coming to an end.

A symptom of the growing supply difficulties is the diversion of effort to less familiar species (see page 36). Thus, for example, landings of round-nosed grenadier (*Macrourus rupestris*), not identified in North Atlantic catch statistics until 1967, are now averaging 30,000 tons per year. In addition the U.S.S.R. and Japan are seeking ways of exploiting krill, and the South Africans have since 1970 been catching substantial quantities of lanternfish.

The exploitation of these unfamiliar and unconventional species offers a challenge to the marketing sector, particularly in the developed countries where consumers are rather conservative and where demand is rather strongly species-specific. Nevertheless, the gradual extension of the cold chain (i.e., the series of cold storage facilities at successive points from landing to consumer) and the increasing sales of frozen fish products, as well as modern marketing and product development techniques, offer the possibility of utilizing these lesser-known species in various minced fish products, such as fish balls and fish cakes.

Such products have been familiar items of consumption in Japan for many years, where fish has been used as a substitute in products more

New products being developed in the U.S. from unconventional species. (NMFS, Northeast Utilization Research Center, Gloucester, Mass.)

normally associated with meat, such as sausage and ham. These products are not much beyond the experimental stage in Western countries and presently have only a very small market share, but in view of their commercial advantages—for example, the possibilities of using different species according to variations in price, as well as the possibilities of utilizing the unconventional species—it seems probable that their market share will grow.

Apart from the expansion of aquaculture (see page 10) and attempts to exploit the less conventional species, pressure on world fishery resources is likely to lead to efforts to make better use of presently known and harvested resources. Among such possibilities are the diversion of certain species now used for reduction to meal and oil to direct use for human consumption, and the utilization of the by-catches of shrimp trawlers. In both cases product development of the type described above can help, although clearly the process of diverting 10 to 20 million tons of roughly the same sort of species from one use to another is unlikely to be accomplished rapidly. Substantial additions to world food supplies are, however, possible from improved processing, storage, and distribution of fish in tropical areas.

In addition to its value as a food, many countries regard their fisheries as a valuable source of foreign exchange, and for a number of countries (e.g., Peru, Iceland, and French Guyana) fishery products are a crucial element in the balance of payments. Although, as for many other

Korean woman with a string of squid, a popular food in the Far East. (FAO)

commodities, a substantial proportion of world trade in fish is between developed countries, both shrimp and fish meal represent important export items for developing countries. Presently the world market for shrimp is depressed, and the quantity of fish meal being traded is less than half of the amount several years ago. Prospects for the recovery of both markets are good, but although further growth in the market for shrimp is possible, expansion of the market for fish meal beyond its pre-crisis levels seems unlikely, in view of the very limited number of unexploited stocks on which a fish meal industry of any magnitude could be based.

Besides the promotion of fisheries as an export industry, many developing countries, e.g., Sri Lanka and Ghana, have embarked on a policy of import replacement, or at least have cut back imports in order to save foreign exchange. By contrast, imports into developed nations have been increasing in recent years, and countries such as the United States, Sweden, Belgium, and Italy now depend on imports for a substantial proportion of their total food fish supplies. Apart from shrimp and other crustaceans, much of the trade still consists of what might be considered the classical items of fisheries trade: cod, and if not herring at least pelagic species, now frozen and canned rather than salted and dried.

Recent trends in the extension of jurisdiction over coastal waters, reinforced by the rising cost of fuel, are making distant water fishing a less attractive proposition, but at the same time are increasing the opportunities for trade (see Figure 3). Presently about 14 percent of the total world catch comes from operations carried out in waters that would come under foreign jurisdiction if agreement is reached on a 200-mile economic zone at the U.N. Conference on the Law of the Sea. Many countries with distant water fleets are already safeguarding their sources of supply by entering into joint venture agreements with local countries—an action that can be doubly beneficial to the coastal state, since it will ensure not only increased foreign exchange but also local employment, an objective that is high on the list of economic priorities in nearly all low-income countries.

It is clear that world fisheries development has reached a critical stage and that prediction of future trends is presently more difficult than at any time in the past thirty years, with uncertainty about not only the magnitude of the world catch but also its international distribution. Some increase can be expected in the total yield of the conventional types of fish currently harvested, and it is fortunate that this will probably occur, for the most part, in waters close to the lower-income countries, where, because of population increase, the need and demand for fish are likely to be greatest. On the other hand, the growing imbalance between supply and demand for the conventional types of fish can be expected to give continued impetus to the exploitation of less familiar species, as well as to research and development in aquaculture. For the foreseeable future, however, the greater part of world fish supplies will continue to come from self-renewing stocks of marine fish, the yield from which will more and more depend critically on the ability of nations, individually or collectively, to manage rationally the living resources of the world's oceans.

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The views of the authors are their own and do not necessarily reflect those of FAO.

The South Korean fishing industry provides almost 85 percent of the annual protein requirement of its people and is a major source of foreign exchange. (FAO)

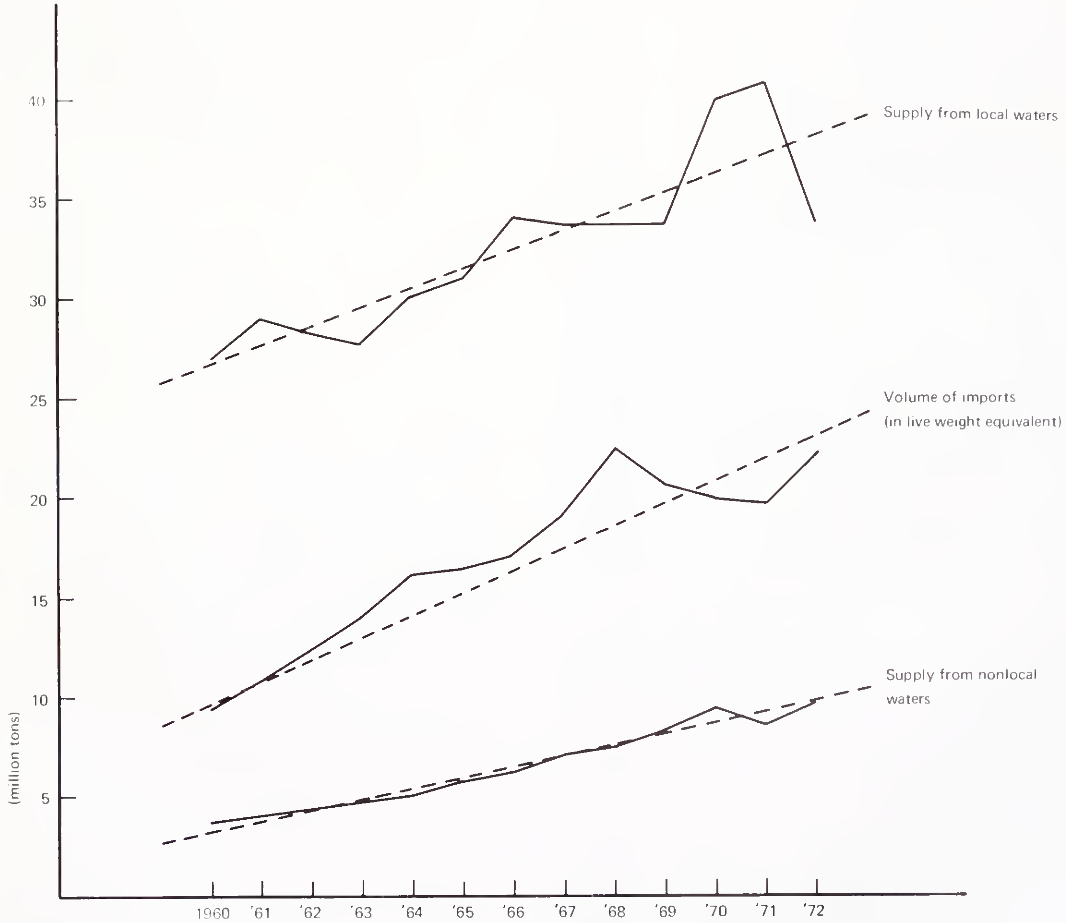


Figure 3. Sources of fish supply, 1960–72. Domestic consumption of fish can be met from three sources: local production (defined as freshwater fish and marine fish taken on grounds nearer to the coasts of a given country than to those of any other country); fishing in waters off the coasts of foreign countries; and imports. Of the three sources, over the period as a whole, imports have been growing the most rapidly, reflecting in part the fish meal boom of the early 1960s and more recently the inability of other sources of supply to meet the food fish needs of such large consuming countries as Japan and the U.S. Distant water fishing, although growing steadily and of major concern to a few countries, e.g., the U.S.S.R. and Japan, accounts for only 14 percent of the total world fish production.

Problems in Prediction

L. M. Dickie

Effective management of fisheries must eventually be based on some concept of ecosystem behavior that will permit prediction of the results of our actions. But we seem to be still far from this understanding. The situation is probably best appreciated by those who have watched and sometimes tried to anticipate the dizzying course of fishery development in the past quarter century—the rapid regrowth of European and Asian fisheries after the war; the birth and growth of the South American anchoveta fishery; the steady and inexorable spread of the distant water fleets to the Northwest Atlantic, the redfish and Alaska pollock fisheries of the North Pacific, the hake fisheries of Africa, and the high-seas tuna fisheries. The tone was set by the anchoveta fishery, which from almost nothing in 1950 grew steadily throughout the late 1950s and the 1960s, expanding year after year to become by 1970 the world's largest fishery. In that year this single species, fished in a single region of the oceans, yielded an unprecedented 12 million metric tons, nearly 18 percent of the world's total annual fish production.

There were, of course, those who expressed concern for this "unbridled" growth. If the upper limit, the natural maximum sustained yield, could be predicted, irreparable overfishing and destruction of stocks might be avoided—or at least anticipated, thereby escaping some of the worst aspects of economic dislocation as the limit was approached. In the wisdom of retrospect it is evident that even the most intelligent and well-meant concern developed a remarkably set pattern that did little to win the confidence of the skeptical, pragmatic fishing industries. At least twice during the 1950s "available knowledge" was used to estimate the upper limit at something approaching double the existing levels of world catch. In each case the predicted upper limit was reached and exceeded within ten years. Revised estimates of maximum sustained yield were made in the early 1960s and again predicted almost a doubling of catch to approximately 60 million tons. But this level was realized by 1967, and in 1970 the world catch had reached nearly 70 million tons, due partly to the opening of fisheries in new areas and on species that had not previously been fished commercially, but partly by unanticipated increases in traditional fisheries.

By the early 1970s a series of new calculations was made at the request of the U.N. Food and Agriculture Organization (FAO), which, in light of its concern with potential world food shortages, had assembled more detailed and up-to-date information on world fisheries. This time a number of independent estimates placed the upper limit at between 90 and 120 million tons, a slightly more conservative extrapolation than had been made (and exceeded) earlier. However, by 1972, after a number of years of relatively constant catches, the anchoveta fishery experienced a decline as dramatic as had been its rise. A drop in anchoveta catch of the order of 50 percent in a year was not compensated by development elsewhere, and the world total catch dropped to less than 66 million tons. More recent statistics may well confirm a reverse trend, at least on a short-term basis.

As each estimated upper limit was approached and exceeded, the observer of this development might be forgiven a sense of drama comparable to that of a gigantic roulette game in which new players continually joined and left their winnings exposed on the table in the hopes of doubling them again and again in "one more" lucky play. So too is it understandable that even if the predictions of possible upper sustained limits were repeatedly proven wrong, there should have been a growing nervousness among the managers and administrators responsible for running the game.

The biologists and economists, to whose lot fell the unwelcome task of diagnosis of fishery conditions, were placed rather in the position of a newly practicing medieval physician whose knowledge of disease was derived from observing the symptoms of his first few patients. In general, they seem healthy enough, but occasionally one of them could abruptly sicken, and some of them

died. If this pace were kept up much longer, surely there was trouble ahead. The question was, how much longer, and what to do about it?

In the absence of any real knowledge of what was critical in sustaining life, let alone what were the symptoms of real disorder, the medieval physician found that a touch of homeopathy was often the most effective medicine, possibly because it most readily convinced the patient that he was being cured. In the fisheries of the early 1970s, the Northwest Atlantic had already experienced a spreading series of fluctuations, and decline of the anchoveta fishery gave an added fillip to the managers' concern. The "reasonable" solution, which found a remarkably rapid and widespread agreement, was the institution of nationally assigned quotas, designed to simplify the complex administrative task of a further orderly cutback in the size of catch, hence in the amount of fishing devoted to the stocks. Promulgation of the regulations from region to region and species to species followed surprisingly easily. At the present time it appears that a new phase of fishery development may be under way. In this phase the gradually declining catch is now at least partly a result of regulation. That is, it has become difficult to establish whether the symptoms of the patient are more a function of the disease or of the cure. In such a situation an improvement in diagnosis is clearly dependent on a better knowledge of the nature of disease and the means through which the symptoms are produced.

Economic and Environmental Changes

There are many symptoms of change that create difficulties in fisheries but that do not necessarily indicate that fishing is having any undue effects on the basic natural production system. Improved knowledge of the oceans and the biological systems in them, and of the fisheries themselves, is increasingly enabling identification and understanding of these situations so that means may be found for the best management.

Quite naturally the common cause for alarm is a drop in average catches by individual boats, without compensatory price increases. The problem is most often an economic one. As fishing increases, the average abundance of the fish population goes down, not because fewer young fish are born into the stocks but simply because fish live for a shorter time than they did when there was no fishing. That is, total catches rise because more boats are fishing, but the catch of individual boats falls, and the average size of fish caught also decreases. These effects are hardly noticeable in early stages of fisheries partly because there is so much variability in catch from place to place and time to time. Furthermore, at the beginning fishermen learn more about the fish and make many small improvements in their fishing gear so that occasional catches are high and costs are kept down. Eventually, however, the long-term trend of decreased abundance and size is felt, and the cost of improved technology, used in the attempt to keep catches high, becomes greater than the extra income earned from using it. The resulting difficulties are usually ascribed to overfishing, and there are immediate calls for "conservation" to correct what is basically an economic problem.

It has taken many years for it to become widely realized that economic difficulties, due to unnecessary and unproductive competition among fishing units, usually arise long before there are any signs of "biological" overfishing; that is, long before the productivity of the stocks may be affected. However, with this realization, the national fisheries administrator is generally presented with a clear

Sorting and measuring the catch. (Robert K. Brigham, NMFS)

RUFAS II (Remote Underwater Fisheries Assessment System), now in a documentation stage, is a sled-shaped vehicle designed to survey bottom resources to 400 fathoms. It can transmit televised observations to the mother ship. (W. R. Seidel, NMFS, Harvesting Technology Task, Pascagoula, Miss.)

solution to his management problem. Not only does it appear to him that there may be dangers to natural production in permitting unrestricted fishing, but there can be at least temporary rewards to the economy as a whole by restricting fishing. The successful results of regulation of such fisheries as the British Columbia salmon fishery, in accordance with economic theories, seem certain to speed the adoption of similar restrictions elsewhere.

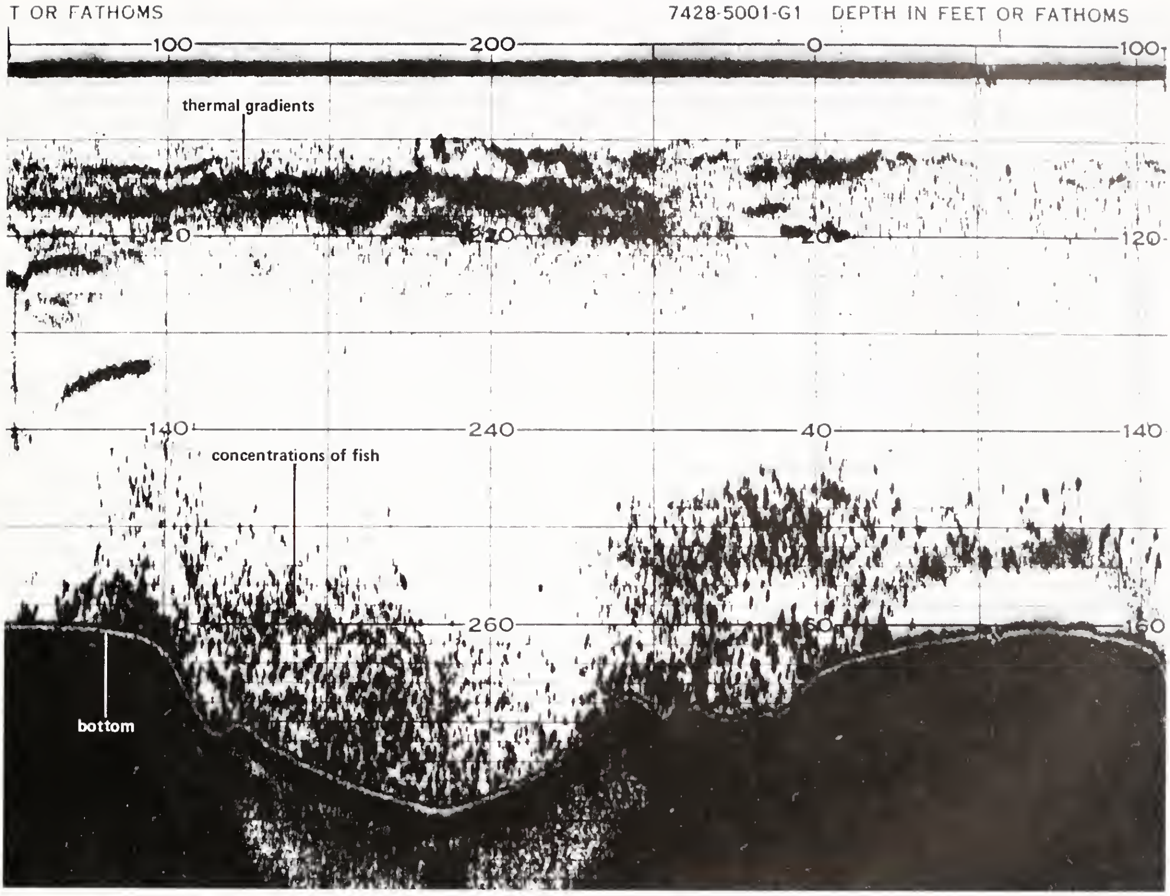
In other situations it has become clear from recent experience that changes in physical oceanographic conditions may have important effects on catch. Where these environmental changes are related to climatic trends, there may be marked long-term catch trends that are quite independent of the effects of fishing. Recent changes in the severity of ice conditions in the Northwest Atlantic are a current simple example. The increasingly difficult winter and spring ice conditions along the Greenland, Labrador, and northeast Newfoundland coasts during the past three years have denied the fishing fleets access to some stocks that had been fished regularly during the recent twenty-year "warm" period. It is not clear whether this climatic trend has also affected the abundance and productivity of the cod stocks of the area, since in the past, fisheries scientists have had to depend on commercial fisheries for data that can be used for estimating abundance. When there is a major change in the distribution of the fleet on the fishing stocks, abundance estimates made in this way become useless, simply because there is no way to determine whether or not the same fish stocks are being sampled. Improved knowledge of climatic effects will depend on development of direct inventory methods, such as the acoustic fish counters now being tested.

The drop in the catch of the South American anchoveta fishery is another example of the effects of environmental change, as it is clearly related to one of the periodic changes in the ocean surface-current system, known as El Niño. The distribution of the fish, in addition to their abundance, has been affected, although once again it is difficult to measure the magnitude of the change of abundance in various areas or to assess the effects it may have on the spawning stocks and on the recovery rate of the fishery.

The primary difficulty faced by the biological oceanographer in analyzing changes in fisheries is that the effects that arise from both economic and environmental causes look very nearly the same as those that would result if excessive fishing were damaging the stock productivity. Given a world situation in which economic difficulties are almost the rule rather than the exception, and where there are widespread predictions that climate is at the beginning of a long downward trend in temperatures, to say nothing of the dangers of pollution, must it be concluded from the present decline in catches that the world high-seas fisheries have reached a practical upper limit to the sustained yield? An answer to this question becomes especially urgent in the present situation where more and more of the world's fisheries are subject to regulations on economic grounds, but often with the claim that restrictions are necessary in the interest of conservation, at a time when there is increased world need for protein foods.

Biological Dynamics

While economic and climatic studies can help explain short-term trends in yield, in the long term the estimation of maximum sustained yield depends on studies of the dynamics of the biological system. The fact that many of the past estimates have proven much too conservative is no cause for present complacency. But to suggest that a downturn in yields means that the limit has been reached is a little like anticipating Armageddon when a new comet is spotted heading our way. The fact is that our knowledge of biological systems in the oceans



Typical tracing (top) from a Raytheon DE-731 depth sounder/recorder (bottom, at left) showing thermal gradients, heavy concentrations of fish, and bottom contour. The scale used is 0-60 fathoms. Acoustical fish-finding devices may be used for assessment as well as exploitation. (Raytheon Marine Company, Manchester, N.H.)

is still a little like our knowledge of terrestrial biology a century ago, or of astronomy before Kepler. Unfortunately the rate of development of this knowledge is also very slow, and governments and the general public, which need answers in order to avoid waste, are still reluctant to bear the high costs of increasing the rate of discovery.

There have been two basic approaches to fisheries prediction, based on the study of biological dynamics. The first method is conceptually simple, although practically very difficult. It is to identify a stock of fish that is commercially exploited, and calculate the rates of input (reproduction and growth) and output (natural mortality and yield) and the population abundance. Simple models can then be constructed that indicate how the yield should change with fishing, and management brought into effect that will maximize an

appropriate measure of yield or yield efficiency (e.g., yield per unit cost of fishing). However, as noted earlier, it has rarely been possible to make direct estimates of abundance. Instead, it is assumed that the fishery effectively samples the entire stock, so that relative abundance changes may be measured as changes in average density. These changes in density must then be studied in relation to changes in fishing and environmental parameters. Unfortunately the densities of fish are highly variable, and fishermen strive to be as selective as possible in their fishing patterns. It is hardly surprising that fishing effects assessed from fishing data alone are very nearly impossible to "test" in short-term experiments, or that predictions of relative abundance change should rarely be convertible to useful measures of actual short-term catch trends. Furthermore, the estimation of the effective sizes of annual broods of fish that will be recruited to the fished populations is notoriously difficult, so that even prediction of the effects of the biological dynamics alone on yield is in relative terms, such as yield of fish per recruit to the stock.

It is not difficult to see that predictions of actual sustained yields for particular fisheries, based on information of this type, cannot be very precise. In the absence of direct observations and better methods, attempts are nevertheless made to apply them to fisheries the world over, as guides to the possible need for regulation. They are regularly used in attempts to set catch quotas that will satisfy the "requirements" of management. It can only be hoped that more reliable methods of sampling and measuring abundance can be quickly developed and applied. At the moment one can only speculate that the risk of waste of potential fish resources from overrestriction must be equal to the possibility that stock production is being "protected" from overfishing.

The difficulty of predicting world catch from a summary of information of this sort on all of the known fisheries of the world is clearly enormous. Yet the task was undertaken by the World Indicative Plan of FAO. Experts were convened to make estimates for all major fish species in all major fishing areas. The answers were corrected by guesses as to the yields of unexploited species that might be fished, and cross-checked by any other information available. It is difficult to judge the utility of their conclusion that sustained yields might approach a doubling of existing catch levels.

Besides the technical problems affecting the precision of the yield-per-recruit methodologies, there are a number of questions as to their applicability. Biological populations are generally considered to be highly "interactive," or as competitors for food and space, in predator-prey relationships and in reproduction. Despite considerable work on natural populations during the International Biological Program, it has yet to be verified that current knowledge is sufficient to permit useful prediction for these complicated systems through use of nearly as complex and detailed models. There appears to be good reason to search for alternative methods of analysis.

The second basic approach used to predict the upper limit to sustained world fish catches may be called the food-chain method. It is directly analogous to the agricultural practice of calculating from known rates of grass production, food intake, and growth efficiency the yield of cows that can be realized from a given area of pasture land. In the case of the oceans, there have been a number of measurements made of the primary production, and attempts made to use them to characterize various production zones. Great difficulty arises, however, when an attempt is made within zones to calculate the utilization of the basic food supply for yields. Biological populations in the sea seem to be even more complex than those on land, and the source of food for any given species is difficult to ascertain because of complicated life-history patterns and scattered distributions of the predators and their prey. Actually calculating the food intakes and growth efficiencies for any one system is a formidable undertaking of which there are nevertheless a number of interesting local examples.

For predicting world catches from food chains, no attempts have been made at detailed analyses and additions of various "links" in the chains. Instead, the links are treated as internally homogeneous, and characteristic rates of utilization and conversion are derived from the local experiments and observations. Identification of the real number of energy transfers, that is, of the number of links in the chains, as well as of the utilization and conversion efficiencies, is critical. So too is the accuracy of the measure of basic production. Uncertainties in all of these parameters must be added to the problems of geographical weightings of zones and corrections for seasonalities or other time variations. It is not difficult to understand why the range of sustained yields, which can be and have been predicted by this method, should be so wide.

Clearly, the amount of personal judgment needed to supplement the sparse information that can be supplied from observations of food chains is too great to permit any very precise conclusions to be drawn at the present time. However, the need

to make estimates as a guide to future policy is great. Therefore, despite the general recognition of the weakness of both the data and the methods, and of knowledge that the food-chain method has been used to give wrong estimates in the past, scientists are repeatedly tempted to make new trys as the information improves. Claims that "reasonable" parameter values give similar estimates from both food-chain and yield-per-recruit methods can do very little to increase confidence in them at present and underline even more the urgency for improved knowledge.

Prospects for Prediction

While the foregoing account emphasizes the deficiencies in the present capacity to provide useful estimates of maximum sustained yields, it is not intended to present a pessimistic view of the prospects. The attempts to develop and use these two basic models, with variations, have measurably improved an understanding of their weaknesses and of how to set about improving them. For example, even though the two models may seem at first to result in similar predictions of maximum sustained yield, their basic construction emphasizes different aspects of the biological systems. In their simplest forms they actually give quite different predictions as to how much fishing or what kinds of fishing technology would be required to achieve that maximum. However, this apparent disagreement is not so much a result of logical inconsistencies between the two approaches as a reflection of the different weightings that the models assign to the complexity of biological interaction with changes in fishing technology. Such analyses have therefore been invaluable in directing the attention of oceanographic research toward the problem of providing measurements of the degree of interaction in populations, rather than the expensive alternative of the accumulation of vast amounts of detail on more and more systems.

The attempts in the food-chain studies to classify the estimates of primary production into zones that have particular significance to fisheries has drawn explicit attention to the overwhelming importance of the small continental shelf areas and of the even smaller coastal strips. By contrast, the great expanses of the open oceans seem a vast biological desert. However, as knowledge of the nearer-shore areas has grown, so too has the realization of their basic heterogeneity and the fact that the high production of the margins is related in specific ways to these complexities of local upwellings, gyres, or eddies. Is it reasonable to suppose that the complexities of the great ocean basins, which have shown up in recent geophysical researches, and growing knowledge of the complexity of the ocean currents, will eventually lead us to see the significant biological structure of this apparent desert? Large whales, giant squids, tuna, and many other creatures have learned to live in it presumably by exploiting its special features. There seems, then, some prospect that better knowledge of the open oceans will show greater potential usefulness than has been indicated by general explorations to date.

But possibly the most important things being learned in the attempts to predict biological systems in the sea concern the remarkable complexity of their structure. The food chains are apparently longer and the life histories of predator-prey relations more complicated than has been the experience on land. In addition, the structure of communities in this dense but mobile, three-dimensional world is dependent on the turbulent structure of their physical environment to a degree that is foreign to terrestrial life, where much of the significant structure is provided by living vegetation.

In this shifting, watery world, it is becoming clearer that there may be no single simple answer to the question, "How much can we take?" With such interactions, the productivity at any one level seems likely to depend on the degree of exploitation and structure at other levels. That is, maximum sustained yields are a complex function of biological dynamics, the structure of the physical environment, and the economics and technology of the exploitation system. Almost all that can be said at the moment is that both the rate of production and the natural rates of exploitation at lower levels in the food chains are orders of magnitude greater than they are among the levels now harvested. However, this enormous production and successful exploitation are carried on by small organisms that themselves have greatly magnified rates of turnover. Our capacity to make practical use of them will be limited by our technological ability to find or develop methods that can capture and accumulate these large energy cascades. Aquaculture systems at the sea edges, based on filter-feeding molluscs, are one example of the possible means for doing it in that special environment (see page 10). The large animals of the open ocean have found other ways. It is difficult not to suppose that further knowledge of the biological systems and of the environment in which they operate will eventually suggest novel but useful possibilities for increased food production.

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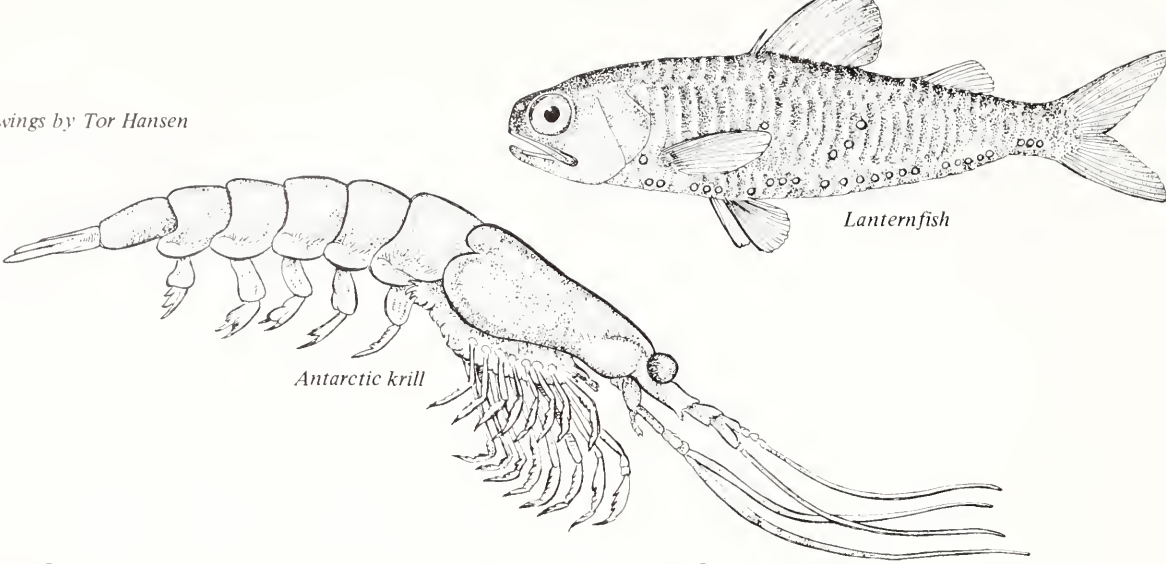
Drawings by Tor Hansen



Unconventional Harvest

As we come down the homestretch in the twentieth century, two areas have emerged as serious challenges to man's ingenuity. One is the identification and development of energy sources; the other is supplying food for the increasing multitudes. In discussions of the food problem, the sea is often mentioned as a source of significant additional supplies of protein. It is this pronunciation that frequently triggers debate among fisheries specialists throughout the world.

With conventional harvesting techniques applied to traditionally accepted species of fish and other marine animals, the present world catch for food is about 50 million tons. Recent estimates provided by the U.N. Food and Agriculture Organization suggest that a doubling of this figure—over 100 million tons—is within the realm of reality. To reach such a goal, certain requirements must be met, including expansion of fishing effort in the Southern Hemisphere and other areas of the world where maximum exploitation has not been attained; new harvesting techniques; and increased exploitation of the ocean beyond the Continental Shelf.

In addition to expanded geographic coverage by fishermen, food processing and product development are important components of any plan to increase production of food from the sea. Among the candidates for this accelerated production are fish, crustaceans, and molluscs.

Fish

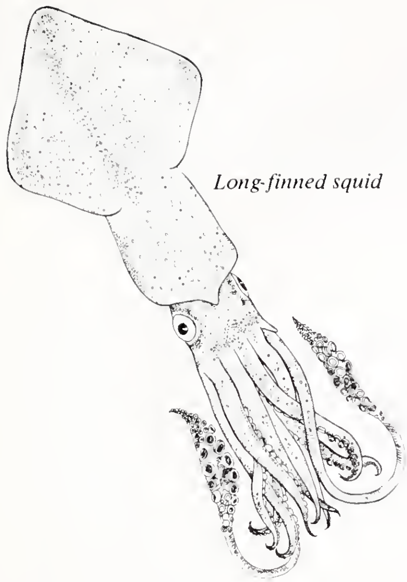
To increase the yield of fish available as food either directly or in the form of concentrated fish protein, we must take advantage of fish now wasted in many trawling operations. Often, more than 30 percent of the catch brought on deck is returned to the sea for reasons of nonmarketability or economics. Another route is being demonstrated by Europeans who are looking into deep-water fishery resources, including a variety of demersal species such as grenadiers and scabbard fish. One recent estimate of these now unused resources suggests an annual production of more than 15 million tons.

Other unconventional species are found among coastal and oceanic pelagic fishes. Recent developments off South Africa demonstrate how advances in harvest technology can broaden the base of available resources. Near Cape Town, a major fishery for reduction products (meal and oil) has, until recently, used mainly sardines and anchovies. Starting in 1969, small amounts of lanternfish entered the catch; by 1973 this "exotic" accounted for more than 10 percent (43,000 metric tons) of the total production of the fishery, thus providing a breakthrough in species utilization. Depending on development of adequate technology, an additional 20 million tons of coastal and oceanic pelagic fish may be harvestable.

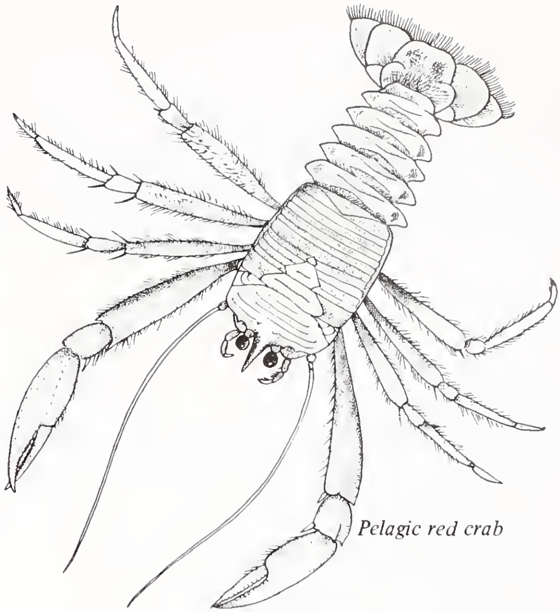
Crustaceans

Among the vast oceanic plankton resources being considered for direct use by mankind, crustaceans are of particular interest because, collectively, they represent a large part of the plankton population, which is the base of the pyramid of animal life in the sea.

The crustacean most often discussed in this context is the Antarctic krill. Many agree on a potentially available harvest of more than 25



Long-finned squid



Pelagic red crab

million tons per year. The Soviets have been experimenting with krill harvesting for over 10 years, and recent work with large pelagic trawls indicates catches of up to 20 tons/hour. Krill have been prepared as a "spread" for human consumption and as animal fodder. The Japanese have sent two expeditions to the Antarctic for krill during the 1974-75 season. Production targets are about 3000 tons.

The galetheid crab, particularly abundant in the Eastern Pacific and the sub-Antarctic, is beginning to be commercially exploited. Utilization in Chile is as a form of "langostino," in both frozen and canned form. This pelagic crustacean may also be used as a food additive, providing nourishment and flavor.

Molluscs

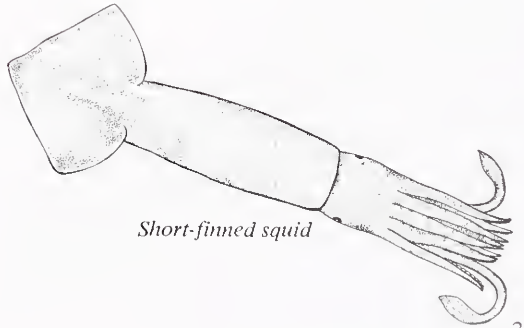
An important potential resource is represented by the cephalopods: squid, octopus, and cuttlefish. Yields from the continental shelf areas of the world are estimated at more than 7 million tons/year, which is almost five times the present landings. These interesting shellfish are highly esteemed by many Europeans and Asians, among others. One of the features that makes them an attractive product is the comparatively high yield of edible flesh—about 80 percent versus 20-50 percent for many other marine forms.

In terms of maximum utilization and efficiency of the food-producing capability of the world's oceans, the forms mentioned tend to be more productive than predators higher in the food chain. They are more directly dependent on the ocean plant community (diatoms) and thereby represent less nutrient conversion loss than, for example, codfish, tuna, and whales.

Utilization

There are problems associated with the proposed targets discussed above. Not the least of these involves the management or manipulation of common marine resources on an equitable and humanitarian basis. The techniques of harvesting are probably not as insurmountable as one might think. New concepts are being developed, including aggregation or herding of populations by light, sound, or other mechanisms. Application of recently evolved food processing methods, including production of concentrated protein and the separation of flesh from other components (bone, viscera, etc.), represents a positive step in seriously considering small, complex animals for mass consumption.

The real challenge in the full utilization of potential ocean food resources is developing the interdisciplinary orchestration, from oceanographer to economist.—WARREN F. RATHJEN, *Program Manager, New England Fisheries Development Program, NMFS, Gloucester, Mass.*



Short-finned squid

The View from New

"If it was oil, we'd of had 200 miles long ago," said a Gloucester fisherman. "But we don't have 200 miles and without it there's no future. Look at the farmers and their subsidies. Look at the oil industry; they can drill for oil knowing that no Russians are going to start drilling next to them. But for a fisherman, everywhere he looks there are Russians, Germans, Poles, Spanish, and Japanese fishing."

A New Bedford fisherman remembered, "It used to be ten, fifteen, or—for me—even thirty years ago we'd go out for eight or ten days and load up that boat with fish. Maybe 120,000 pounds, maybe more. Used to be you could get a million pounds of fish at the auction on a Monday morning. Now, if you're lucky, you'll bring in forty or fifty thousand pounds. More like twenty-five or thirty thousand lately. Same number of days, same amount of fuel—'course, the price of fuel is way up. Everything is way up: twine, cable, labor costs on repairs, and food. Everything but the price of fish."

The men fishing out of the small Cape Cod port of Chatham see the problem a little differently. "We're just day fishermen here," said one. "Only go out one day. Leave about three or four in the morning and come back before six that night. Not like the big boats that go out for a week. We can't take the bad weather the way they can."

Few of these boats go more than 20 or 30 miles from shore (they go after groundfish—cod, pollock, haddock, halibut—by a method called long-lining or line-trawling), but they too are affected by the intensive foreign fishing. Not only must they put up with direct competition for the fish stocks, they must also cope with loss of gear. On numerous occasions, foreign vessels have ignored markers and dragged their trawls through the set gear. Although better gear markings, radio contact, claims boards, and political pressure have helped reduce or offset such losses, the foreigners are still out their catching fish. "The Germans have been concentrating on those herring stocks," complained a Boston fisherman. "Well, the fish we catch eat those herring and the mackerel. If the foreigners go and catch them all, what do the codfish, the haddock have to eat?"

It is difficult to talk with New England fishermen these days without having the conversation snag on the spiny issue of the 200-mile fishing limit. Those who fish as well as those who regulate fishing are at a loss to predict just what will develop from the United Nations Law of the Sea Conference (see page 42), domestic legislation in the form of the Studds-Magnuson bill (proposing unilateral U.S. adoption of a 200-mile economic zone) and the High Seas Fisheries Management Act, or other measures yet to come. As things now stand, the five New England states with commercial marine fishing interests (Vermont has none) have jurisdiction over a three-mile territorial sea. Each state licenses vessels and promulgates regulations affecting fishermen who land fish in its ports. The National Marine Fisheries Service (NMFS) is responsible for the preservation of the fishery, including the encouragement of sound fishery management strategies by commercial fishermen and fish processors. A cooperative program between the New England states and NMFS has been established to study means of controlling resources common to those states.

At the international level, management of fish stocks through quotas on individual species is being attempted by the seventeen-nation International Commission for the Northwest Atlantic Fisheries (ICNAF). (Nations signatory to the ICNAF convention are Bulgaria, Canada, Denmark, Federal Republic of Germany, France, German Democratic Republic, Iceland, Italy, Japan, Norway, Poland, Portugal, Romania, Spain, United Kingdom, U.S.S.R., and U.S.) Some of the indecision affecting state and federal agencies in this country is also evident within ICNAF. At its meeting last June in Halifax, Nova Scotia, both the U.S. and Canada claimed their rights as coastal states to fish for as much as they were able to catch. Others at the meeting held back approval of this coastal states' preference approach to see what might happen at the impending Caracas meeting of the Law of the Sea Conference. Although no agreement was reached at Caracas, further recognition

Provincetown fishermen mending nets. (Eugene A. Eisner, Photo Researchers)

Bedford

Susan B. Peterson

of coastal states' control over the fish stocks was given at a special ICNAF meeting in November 1974, indicating growing international acceptance of a 200-mile limit.

Not many New England fishermen want to shut out foreign fishing entirely. Most realize that though they themselves have fished the rich waters over Georges Bank for several hundred years, they were preceded by Spanish and Portuguese in search of cod. There is general willingness to accept historical fishing rights within an extended jurisdictional regime. And there is also the realization that since current fleet capabilities make it impossible for Americans to catch all available fish off Georges Bank, controlled foreign fishing would have to be allowed under bilateral or multilateral agreement. What galls is the fact that U.S. vessels, which once had Georges Bank pretty much to themselves, now account for only 16 percent of the harvest. Sixteen foreign nations take the rest.

There is a good deal of talk about renovating the New England fleet and expanding markets at home and abroad. Yet during the six months I recently spent talking with boat captains, boat owners, and fish processors in the Massachusetts port of New Bedford, I found few men willing to make large-scale changes in their businesses today—not in the face of the enormous uncertainty about the future of fish stocks and their management. Of the twelve fish processors in New Bedford, five have built new facilities in the past five years, and two have remodeled. These investments in the future began when fish stocks were still somewhat plentiful and wholesale prices were increasing (see Table 1).

Table 1

New Bedford Landings

Year	Total Pounds	Value ($)
1973	63,086,894	$17,357,179
1972	60,844,397	18,331,244
1971	73,745,962	16,435,439
1970	111,282,310	19,574,846
1969	108,214,570	17,402,237
1968	126,098,504	18,908,882
1967	117,842,010	15,422,709
1966	133,497,454	18,688,586
1965	147,315,816	19,805,302
1964	135,722,564	16,748,014
1963	135,148,620	16,804,673

Source: NMFS, New Bedford.

Today labor costs are rising rapidly, as are costs of equipment and supplies. For example, it cost twenty-five cents per pound of fish fillets to cover these particular expenses in the mid-1960s. Now it costs from thirty-five to forty cents per pound, and the volume of fish has fallen off markedly.

In an attempt to increase the volume of fish that the New England fishermen bring to port, NMFS and industry leaders have established a task force to explore the catching, processing, and marketing of underutilized species, such as squid, mixed species, and red crab. While this program is a new one, it seems that fish dealers—at least those in New Bedford—do not yet consider these species as viable marketing alternatives. Their reasoning is based on the peculiarities of a highly perishable product and its unpredictable supply. When it comes to reducing risks in a highly risky business, they prefer to handle a product with which their employees and customers are familiar. They want fish whose changes in quality and quantity are relatively predictable through the year, fish like ocean perch or pollock that can sell at prices equal to or below those of meat and poultry. One could argue, of course, that diversification also reduces risks by spreading them over a greater number of products. But the dealers, although faced with lower volumes of traditional stocks, are holding their ground.

At first glance, the fishing vessels of New Bedford appear outmoded—wooden side trawlers built for fishing as it was fifty years ago. However, about one-third of the boats are less than ten years old, and there are some steel stern trawlers, modeled on the foreign vessels, that began fishing off New England in the early sixties. Although these expensive ($300,000-$800,000) vessels continue to enter the fishing fleet, the economic situation has changed so drastically within the last five years that in spite of high prices for fish, reduced volume makes older wooden boats competitive with modern ones. The newcomers frequently have high operating expenses because of larger engines, and higher mortgages and dry-docking costs.

Critics of the New England fishing industry question the sense of caution and conservatism in the ports that appears to stifle competition with the foreigners. They often deride the New Englanders because much of the fish imported into the U.S. (now accounting for more than 50 percent of the total consumed) comes from under their noses. But, in fact, New England vessels provide a product the others cannot. Whereas the foreign fleets must salt, can, freeze, or otherwise process their catch and haul it home as high-volume,

low-priced products, the American heavily ices his fish, providing it with a moist, cold environment that preserves the freshness, and lands it generally within ten days after it is caught, as a low-volume, high-priced product. Within 200 miles of their own coast, New England fishermen do not need factory ships, which coincides with their preference for small boats. Furthermore, although most have a desire to be at sea that is hard for them to express, they also prefer frequent trips home to see their families and to participate in varied shoreside activities. Factory ships that spend six months at sea do not suit the tastes of these men.

I do not intend to leave the impression that the New England fleet is stagnant. In spite of their doubts about the future of the resources on which they depend, a number of fishermen are innovating—building new boats and experimenting with new net designs or with products usually not landed in American ports; squid, herring, pout, scup, and monkfish have all been included in the catch of New Bedford–based vessels of late, though, as indicated earlier, not yet on a commercial basis. Perhaps of greatest importance is the number of men who indicate a desire to innovate once trends in fisheries management become clear. Of the thirty New Bedford boat captains I talked with, eight began their discussion of innovation with a variation on the phrase, "If I knew what was going to happen with the foreigners, 200 miles and all that . . ."

As extended jurisdiction resulting from either domestic or international action becomes more likely, boat owners and fish processors are increasingly turning their attention to the need to put their own industry in order. It seems to them that if a 200-mile economic zone is established, new boats will be encouraged to enter the fishery. This will further cut the volume available to boats already fishing, and perhaps put even greater pressure on such threatened species as haddock and yellowtail flounder. Thus, they see a need for a management program that will control the exploitation of fish stocks and deter further hardship in the industry by regulating the fishing effort. Rather than discouraging young men and new vessels from going fishing in the future, those who fish today would like to see a carefully regulated increase in the domestic fleet as stocks now exploited by foreign vessels are made more readily available to the New Englanders.

(Top) Some of the ships in the large foreign fleets that concentrate on primary fishing grounds. This is the scene facing U.S. fishermen in the Northwest Atlantic and North Pacific. (Bottom) A large catch of herring and mackerel on board a foreign factory stern trawler. Herring and mackerel are the leading species taken in the North Atlantic. (NMFS, Law Enforcement and Marine Mammal Protection Division, Gloucester, Mass.)

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LOS and the Fisheries

James A. Storer and Nancy Bockstael

Inaugural session of the Third U.N. Law of the Sea Conference in Caracas last summer. (UPI)

In recent months, two international meetings have dealt directly or indirectly with the issue of human hunger. In Rome last November, the United Nations World Food Conference drew the attention of governments, public, and the press to the conflict between expanding populations and shrinking food supplies. In Caracas last June, the United Nations Law of the Sea (LOS) Conference took up matters of international law governing the utilization and exploitation of the world's oceans. Though it aroused less public interest, the LOS Conference, which is scheduled to resume in Geneva in March, is likely to have a great impact on future supplies of food, particularly of protein sources.

Though some might hope that the United States could isolate itself from the problem, world food scarcity has already begun to affect Americans—in the marketplace, where their position had been almost unassailable. This is a result not only of population growth but also of the diffusion of the

world's wealth and purchasing power. In ocean affairs, too, the power of international concerns is being felt in this country. It is clear that if a legal regime is created governing the use of the oceans and their resources, it will necessarily represent some degree of compromise, a full share of which must be borne by developed nations.

An International Dilemma

During the 1950s and 1960s, world consumption of fish increased from 21 million to 70 million metric tons. The only foodstuff to expand at a higher rate than that of the world population, fish became an increasingly dominant part of the human diet and an increasingly important source, at least in the developed countries, of low-cost, high-quality animal feed.

All this coincided with the population boom of the past decades and at first sustained hopes that the vast productivity of the oceans would help offset predicted food shortages. But by the middle of the 1960s, one popular food fish after another began showing signs of depletion. In 1970, in an abrupt and unexpected reversal, the industrial fish catch plummeted. Although the food fish harvest has continued to increase modestly since that time, total production has registered a decline for three consecutive years, reflecting the proportional significance of industrial fish–specifically the Peruvian anchoveta–in the total world catch.

The declining rate of production growth has not been accompanied by a similar change in the application of capital and labor resources, i.e., the fishing effort. On the contrary, the soaring demand for protein has resulted in a dramatic expansion in the number of fishing nations and fishing vessels and the consequent intensification of fishing pressure on the world's traditional fishing grounds. The inability of fisheries to meet ever-growing demands, even to maintain present supply levels, can only create additional pressures on the prices of protein sources everywhere.

What effect has the fisheries dilemma had on the United States? American fishermen, though comprising a small percentage of the work force, are hard hit by the depressed condition of coastal fisheries industries (see page 38). The U.S. consumer, although less directly or severely influenced, faces higher prices for fish, as well as for poultry and pork because of shortages of fish meal. But there is another, possibly more dramatic, effect in the offing. It is precisely those stocks off the U.S. coasts that may well be the first to be seriously damaged or destroyed if appropriate steps are not taken. Such an occurrence would be tantamount to foreclosing on all future options for the utilization of these resources.

U.N. Secretary General Kurt Waldheim addresses the opening session of the World Food Conference in Rome last November. At left is Addeke Boerma of Holland, Director General of the U.N. Food and Agriculture Organization; in the center is Sayed Ahmed Marei of Egypt, Secretary General of the conference. (UPI)

Foreign Fishing

Prior to the late 1950s, the waters off the U.S. coasts were fished predominantly by small vessels. By 1960, an influx of large, highly mobile foreign fleets began to appear in the Northwest Atlantic and the North Pacific. Presently, fisheries operations in the Atlantic Ocean heavily exploit all major species from Nova Scotia to Cape Hatteras. The harvest from this area totals about one and one-quarter million metric tons, less than one-fifth of which is attributed to U.S. fishermen.

The North Pacific represents an even more dramatic example of the sudden influx of foreign fishing. The current foreign catch in the area is fifty times that of the U.S. harvest and is taken chiefly by Japan and the U.S.S.R. The first species to be affected by these operations was the yellowfin sole, the annual landings of which declined from 650,000 to 63,000 metric tons in two years. Since then the major target fish have been pollock, ocean perch, and hake. None of these are popular with the U.S. consumer or traditional target species of U.S. fishermen. However, the impact of large-scale foreign fisheries for these species has been disadvantageous for halibut and crab, which are taken incidentally.

It is not true, as is often assumed, that North American coastal stocks were not endangered until the advent of technologically advanced, intensive foreign fishing. U.S. and Canadian halibut fisheries expanded so rapidly in the early 1900s that it became evident even before World War I that

these stocks required protection. Agreement was reached by 1923 establishing the International Pacific Halibut Commission. The decline of the Fraser River salmon after 1913 led to joint U.S.-Canadian investigations and the eventual creation of the International Pacific Salmon Fisheries Commission. In 1949, the International Convention for the Northwest Atlantic Fisheries (ICNAF) was signed, but even before this, substantial declines in the U.S. catch per unit of effort were recorded, particularly for haddock and yellowtail flounder on Georges Bank.

Thus, even before the sudden build-up of foreign fishing, some of the more popular North American species were in difficulty. Why then has so much damage been attributed to foreign fleets? Perhaps because these relatively recent developments have altered two important aspects of the fisheries problem.

The first involves the time horizon available for response. Damage that was once the result of a decade of overfishing can now be accomplished in a season; then the fleets can move on to other stocks in other locations before protective action can be taken. The second aspect concerns the number of parties requiring reconciliation. With the arrival of distant water fleets, the number of nationalities fishing the grounds off U.S. coasts increased dramatically, making effective conservation dependent upon agreement among a large number of participants. The more competitive the search for fish, the less effective were non-distributive types of regulations, such as mesh size, and the more difficult it became, consequently, to agree to any satisfactory measures at all. It is for this very reason that multilateral commissions, with their numerous and diverse membership, have been unable to make effective and timely decisions.

National and International Regulations

In a special meeting in October 1973, ICNAF succeeded in establishing a new system that included national quotas for all important species. The degree to which stocks of haddock are depleted is reflected in the fact that their quotas have been set at zero for the next three years.

Statistics gathered by the commission indicate that in the 1970s, the effort applied

Two Soviet factory stern trawlers tied up alongside a refrigerated transport ship in the North Atlantic. Fish are processed and refrigerated on the 275-foot stern trawlers, then loaded onto the mother ship to be taken to the U.S.S.R. (NMFS, Law Enforcement and Marine Mammal Protection Division, Gloucester, Mass.)

annually to the groundfish of Georges Bank exceeded by more than 30 percent that required to take their maximum sustainable yield. Thus, not only are stocks in serious condition, but substantial amounts of otherwise productive capital and labor are being wasted.

In conjunction with the rapid advances in fisheries operations, the world has witnessed the development of two types of restriction on the freedom of fishing. One is the international fisheries commission, which in its many manifestations has sought to reduce international conflict and protect fisheries resources through regulatory processes without assuming or designating exclusive resource rights. In many respects, as discussed above, these organizations have proved incapable of coping with the problems of marine fisheries. The second type of restriction is the increasing number of unilateral claims to extensive fisheries jurisdiction.

The intent of the LOS Conference is to end this patchwork of national and international regulation and its conflict with the traditions of freedom of access. In its place would be established, on some orderly basis, patterns of jurisdiction to all fisheries of economic interest.

LOS Proposals

The initial substantive negotiating session in Caracas was somewhat disappointing in that few contentious issues were resolved. One of the certainties, however, is that the ultimate treaty will provide for considerable coastal state control over living resources within a wide (probably 200-mile) coastal zone, though the essential features of this area are still matters of disagreement. A number of proposals have been put forward differing substantially on the degree of coastal state authority.

The position of a number of Latin American countries is perhaps the most extreme in this respect, calling for complete sovereignty within the zone. Many of the lesser developed countries have been favorably impressed by the Latin American views. The developing nations have problems in accepting the concept of coastal state duties and desire the right to determine unequivocally the pattern of resource exploitation within their zones. Their ultimate intention, quite understandably, is to effect a redistribution of the exploitation of fishery resources from the developed distant water fishing nations to the developing coastal states.

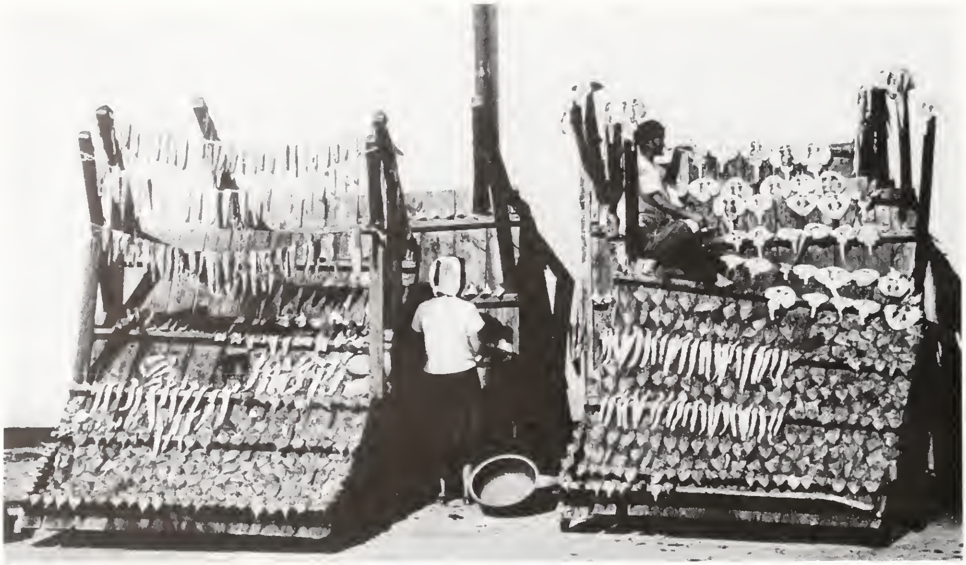
Another major approach to fisheries, proposed by members of the European Economic Community, entrusts fishery organizations of a regional or sectoral type not only with the coordination of scientific research programs but with the determination of conservation principles and adoption of regulatory measures. As such, the range of responsibility and discretion awarded to regional commissions is so great as to minimize coastal state authority over the living resources off its coast.

Among the major distant water fishing nations, the U.S.S.R. and Japan have made less significant departures from the status quo. While acknowledging the economic zone concept, the Soviet position provides the coastal state with only limited preferential rights within its zone.

In the context of these conflicting views, the U.S. position represents something of a compromise. The U.S. draft articles submitted in Caracas provide for a 200-mile economic zone. The coastal state's exclusive right to regulate fishing within this zone, however, is coupled with its international obligation to conserve the stocks and to ensure full utilization. The conservation clause requires that commercial stocks be maintained at or restored to levels that *would allow* maximum sustainable yield (see page 3), and that other stocks be protected from extinction. Full utilization of total allowable catch would be ensured by permitting foreign fishing to the extent that coastal state fishing falls short of the limit.

These principles have often been misinterpreted as requiring utilization *at* the level of maximum sustainable yield (MSY). The intention is that a total allowable catch limit be set by the coastal state for all species of interest and that this limit be such as to make possible the attainment of MSY, but the total allowable catch would generally differ from MSY to accommodate coastal state environmental and economic needs. This deviation from MSY involves consideration of species interrelationships and, perhaps more important, the efficient production of fish and the capture of the resource rent currently lost due to uncontrolled entry.

The U.S. draft articles give special consideration to anadromous and highly migratory fishes whose special biological characteristics preclude management on a zone basis. The articles prohibit high-seas fishing of salmon without the consent of the coastal state and, thus, essentially submit the anadromous fishes to the same jurisdictional authority as coastal species. With respect to highly migratory species, the articles provide for the regulation of stocks within the economic zone by the coastal state and beyond the economic zone by the state of nationality of the vessel, both in accordance with regulations established by



A fish market in South Korea. (FAO)

appropriate international or regional fishing organizations. The mandate of these organizations would include the conservation of stocks, assurance of full utilization, and establishment of "equitable" allocations among member nations.

Considerable differences have arisen over treatment of migratory resources. The importance attached by the Latin American countries to maintaining complete discretion over all fish in their zone has led the U.S. and other distant water tuna fishery countries to take the position that allocations and fee collection must take into account the special interests of coastal states. The ultimate resolution of these differences is difficult to predict.

Geneva and Beyond

The task of resolving the remaining conflicts presents a challenge to LOS negotiators. Many feel that it is a futile exercise since the ultimate result, whether the conference succeeds or fails, will be extended coastal state jurisdiction. Among the proponents of this view, there is a tendency to oversimplify the concept of extended jurisdiction and its implications. It is too often viewed as a mechanism that will automatically restore fishery stocks, revitalize coastal fishing interests, and assure efficient production of a large supply of low-priced fish products.

What will be achieved more or less immediately will be the final dissolution of international adherence to freedom of fishing, and the simultaneous and inevitable distribution of the seas' living wealth. The trend toward exclusivity of the economic zone carries with it a vast redistribution of authority. This, in turn, will create considerable pressures to eliminate distant water fishing, with the attendant expectations that domestic industries will develop.

These pressures have several implications for the production and trade of fishery products. Distant water fleets take a sizeable portion of the world's catch—60 percent of the total catch of all fisheries resources in U.S. coastal waters, and as much as 70 percent of the harvest off Western Africa. The obvious consequences of rapidly phasing out operations of this magnitude include the dislocation both of distant water fleets and of the marketplace.

Even if coastal industries were to respond immediately to the reduction of foreign fishing pressures, traditional sources and trade patterns would be radically disrupted, and the ensuing transitionary period could be disruptive to the supply and price of fish (particularly when coupled with the lower total allowable catch limits for certain popular species, which will be necessary if these stocks are to be allowed to rebuild). One additional effect is possible: if coastal industries are fostered even where foreign fleets would enjoy a real comparative advantage, the industries' prices will be higher than necessary since the most efficient units will be arbitrarily barred from fishing.

These factors could have some important consequences for the U.S. It should be noted, for instance, that in the past several years, the major

portion of the U.S. processing industry has relied almost exclusively on imports for their frozen fillets and frozen blocks and slabs. The domestic coastal industry has maintained a competitive advantage only in fresh-fish markets, from which foreign landings are effectively excluded. Another major concern for the American consumer is the supply of tuna, most of which is caught by U.S. or Japanese distant water operations. The final arrangements for tuna management are still unclear, but they will certainly present greater difficulties of access for the relatively efficient distant water units.

Thus, the advent of a new pattern of jurisdiction over the living resources of the sea is likely to result in some significant disturbances in the supply of fish products. In an era of concern for food, one might question the desirability of any extended jurisdiction. Yet despite the difficulties, it is widely accepted that this is the only means by which the intrinsic problems of world fisheries resources can be solved efficiently and satisfactorily on a long-term basis.

Given the continuing high demand for fish, and given the security of access that an appropriate management system could assure under a regime of coastal state authority, it is not unreasonable to expect industry to respond to the economic incentive. Furthermore, even in the short run, the Law of the Sea agreement can, if appropriately drafted, eliminate some of the chaos of transition to the new legal order and mitigate some of the difficulties that, at least initially, could adversely affect fish production.

It is obvious that national interests will not always be consistent with the best interest of the world community. It also appears evident that even with the best intentions on the part of coastal nations, effective management schemes will be difficult to devise and may be costly to implement. Yet the advent of extended jurisdiction within the context of an overall Law of the Sea treaty presents the opportunity for conservation and efficient production and, as such, provides the greatest hope of achieving the optimum utilization of the seas' living resources.

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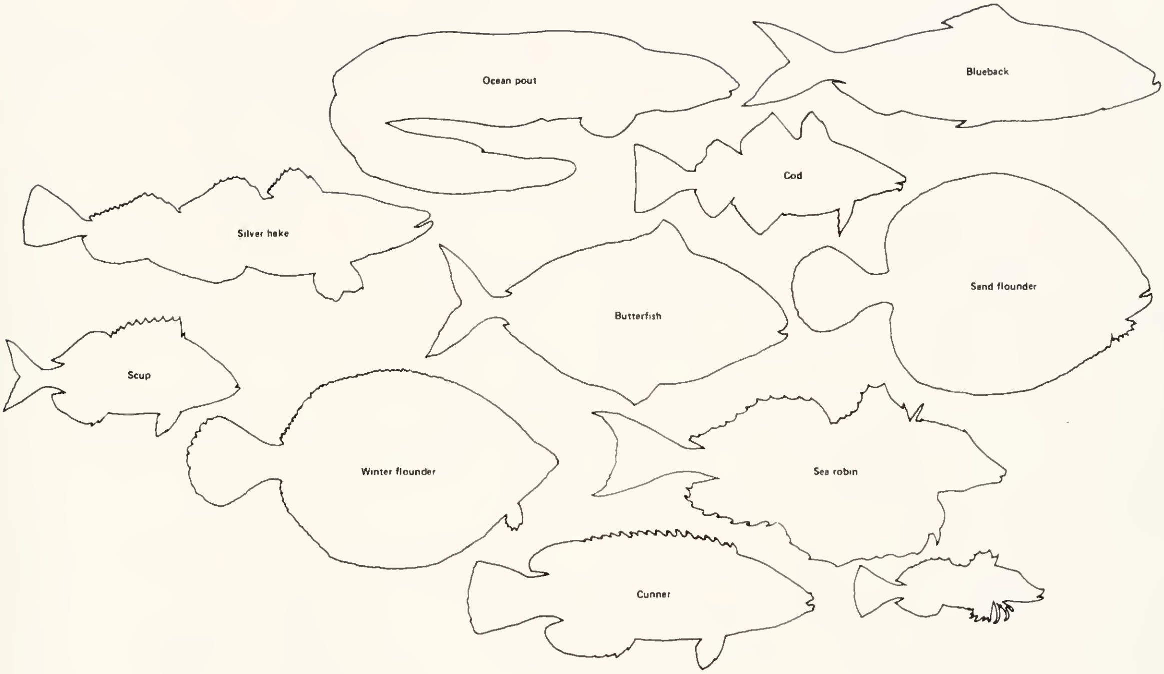
The views of the authors are their own and do not necessarily reflect those of FAO.

Correction

On page 56 of the fall issue, the photo caption indicated ocean dumping of New York City garbage. For the past twenty years, municipal wastes have been unloaded at a landfill site on Staten Island.


Ocean pout
Blueback
Cod
Silver hake
Butterfish
Sand flounder
Scup
Winter flounder
Sea robin
Cunner

W F Gallagher
Blake